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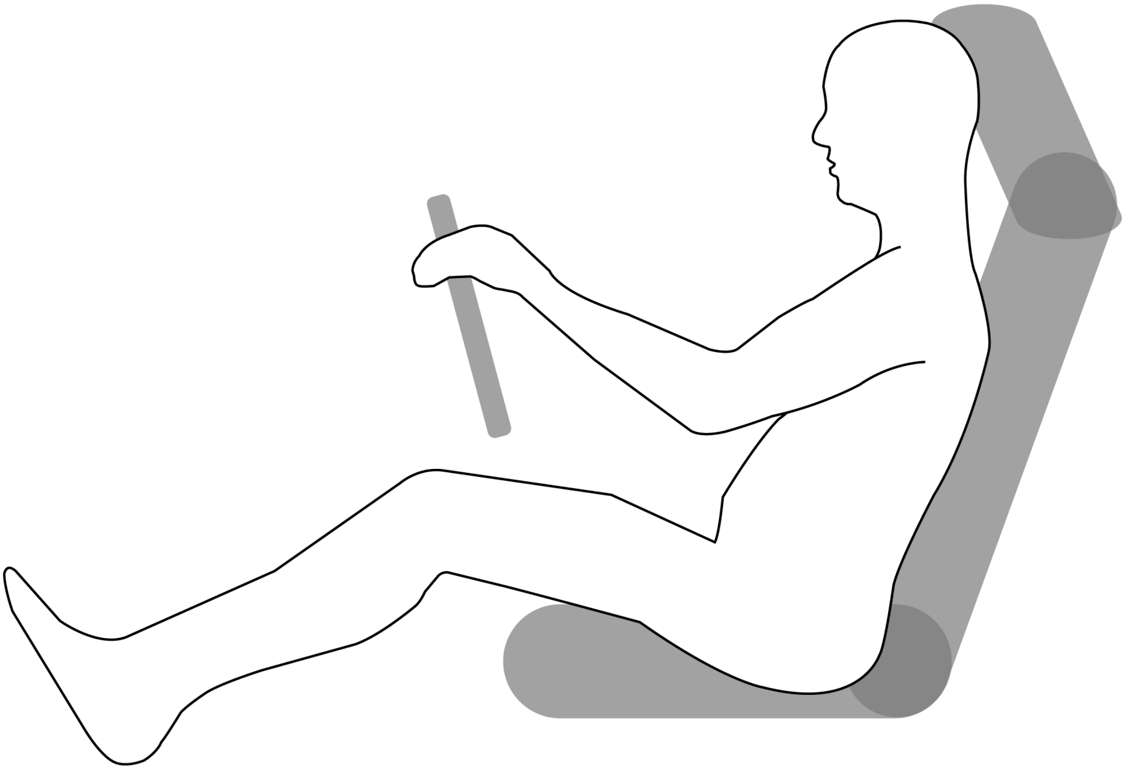

Method development for capturing drivers posture

Method development in automotive ergonomics

Master's thesis in Product Development

Petter Björsell, Johan Ramberg

Department of Product and Production Development
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2016

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Cover: Mediating tool used in workshop 2.

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Excitement

["Something that arouses a strong response from another"]

-Thesaurus, excitement

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Abstract

The vehicle industry is a high competitive market with shifting trends and the pressure on its actors is to constantly bring something new and exiting to the market. There is a need of shorten lead times, reducing cost connected to physical mock-ups and a possibility to evaluate the product with it's users during a early stage in the development process.

Volvo Cars need to collect quantitative data regarding seating postures in Volvo car seats. An identification of suitable technology for gathering data will be made, and a method will be developed based on this technology. This data will later be used in CAE tools for product development. The method will act as a add-on to earlier methods developed at the Volvo cars ergonomics department.

This thesis is divided into two separate parts, one product development part which is the qualitative research. The second part is about collecting quantitative data of seating posture and developing the method.

In the product development stage of the project a prestudy was conducted where the feasibility of the project was evaluated and stakeholder needs were collected. As a final activity in the development stage different tools for measuring the drivers joint angles and posture was evaluated. The technologies that have been examined and evaluated ranges from both analog to digital techniques, such as motion capturing, 3d scanning, and image processing. The final technology chosen for further development are using IMU-sensors to measure the relative motion of the test subjects limbs and predicts the joint angles. In the validation stage the accuracy of the tool was further examined and performance enhancement was also executed in form of design of experiment.

The developed method was used to measure and collect data of 45 test persons in two different cars (a Volvo V40 and a Volvo XC60). To give an indication of how the posture differs between persons with different stature the sample size was divided into three groups with 14 short, 16 average and and 15 tall test persons in each group

Keywords: Product development, Method development, Drivers posture, Joint angles, Motion Capture, Inertial sensors, Automotive, Ergonomics.

Acknowledgements

We would like to thank family and friends, for their support during the whole project. We would also like to thank our supervisor at Chalmers, for the patience and encouragement that helped us achieve the final goal. A special thanks to our supervisors at Volvo cars for their continued support during the whole process, it has been a pleasure. Lastly we would like to thank all the people at the ergonomics department at Volvo cars and at the institution Production and product development at Chalmers.
Petter Björsell, Johan Ramberg, Gothenburg, June 2016

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Glossary

CAD Computer Aided Design.
CAE Computer Aided Engineering.
CAN Controller Area Network.

DHM Digital Human Modeling.

FOV Field of view.

IMU Inertial Measurement Unit.

VR Virtual Reality.

1 Introduction

This chapter work as an introduction to the project method development of capture drivers posture. This chapter contains a project background, method description, aim, limitations and a summary of the prestudy which lays the foundation for this thesis.

1.1 Background

The background to the project method development of capture drivers posture origin's in how today's manikin systems represent a human in a Volvo vehicle.

The Digital Human Modeling (DHM) system used at Volvo cars today is a task driven human model, which means that certain actions must be defined from a user to the model and the system calculates the most probable posture. The posture is calculated with help from an anthropometric database, with respect to the environmental geometry and the defined task. (Rothaug 2000)

The problem that Volvo cars has with the current DHM-system is that the positioning of the manikin is not adapted to the seats in Volvos vehicles. This means that the positioning becomes too general, the seating position is not adapted to a Volvo vehicle.

The task is to explore possible technologies and develop a method for Volvo cars to capture the drivers posture during drive. The new data collection method is going to provide the drivers posture so it can be used to update the current DHM-system. The method are thought to be a compliment to an existing method used by the ergonomics department at Volvo cars. The project has been carried out in two steps like a typical product development project. During the first step possible stakeholders, technologies and prerequisites are identified, to create a solid point of departure before launching the big project. In the second stage of the project a method is developed with selected technology and clinics are performed to capture data.

1.2 Project description

To be able to motivate and clarify the project among the stakeholders of method developing for capturing drivers posture, a clear aim of what the project want to achieve is crucial. The aim of a project can roughly be compared with the impact that the project should have and why it's carried out. To realise the aim of the project it needs to be broken down in smaller pieces and formulated in a way that everyone involved in the project knows what should be delivered, this is called the objectives. When formulating the objective emphasis should be on formulate the objective as clear and simple as possible, keep it real, measurable and rootedness. To evaluate your objectives to see if they support the project a simple S.M.A.R.T-test is good to asses. Each letter in the word S.M.A.R.T stands for different criteria that the objective have to fulfill in order to fit as an objective. The letters stands for Specific, Measurable, Accepted, Realizable and Time specified. (Tonnquist 2012)

1.2.1 Aim

The aim for this project is divided into two parts

- Identify a suitable tool for capturing of joint angles and drivers posture and develop a method that easily can be incorporated in to the ergonomic departments work flow.
- Update the digital human models with new values for their joint angles and new posture in order to improve the virtual prediction model for driver position

1.2.2 Objective

The objectives that are connected to the two aims presented in the previous section

- Identify critical parameters which affects the driver posture in the seat.
- Identify and verify a suitable technology as a data collection tool for the affecting parameters.
- Develop a data collection method for collecting the affected parameters that works as a supplement to current method at the ergonomics department at Volvo cars.
- Perform clinics using a wide range of test subjects to collect subjective and objective data for a selection of different vehicle types.

1.2.3 Limitations

During the project certain limitations had to be applied due to respect to time, budget and equipment. The limitations this thesis had to take into account are listed below

- Only the drivers posture will be studied, no passengers at all
- Only two vehicles will be applied to the tests one "low" vehicle and one "high" vehicle

1.3 Method

This project will be carried out as a product development project. It will consist of a qualitative and quantitative data collection part. The qualitative data collection stage will take place in the prestudy, during the customer needs collection phase. The core stakeholder needs will be captured with two interviews and verified with two workshops. The quantitative data collection stage will be executed in the last stage of the project when a suitable method has been developed.

1.3.1 Process

The product development process that will be used to structure the work in this thesis origin from the generic product development process by Ulrich and Eppinger in the book *product design and development (2012)*. The generic product development process consists of six different phases and each phase have several predefined activities linked to each phase (Ulrich and Eppinger 2012). For this project the generic product development process will be modified and consist of two phases and four stages. The two phases are divide into a method development phase, a verification, and data collection phase. As for the four stages utilized for this project there are planning, concept development, testing and verification of the method and last data collection and for last and result. Picture 1.1 describes the product development process.

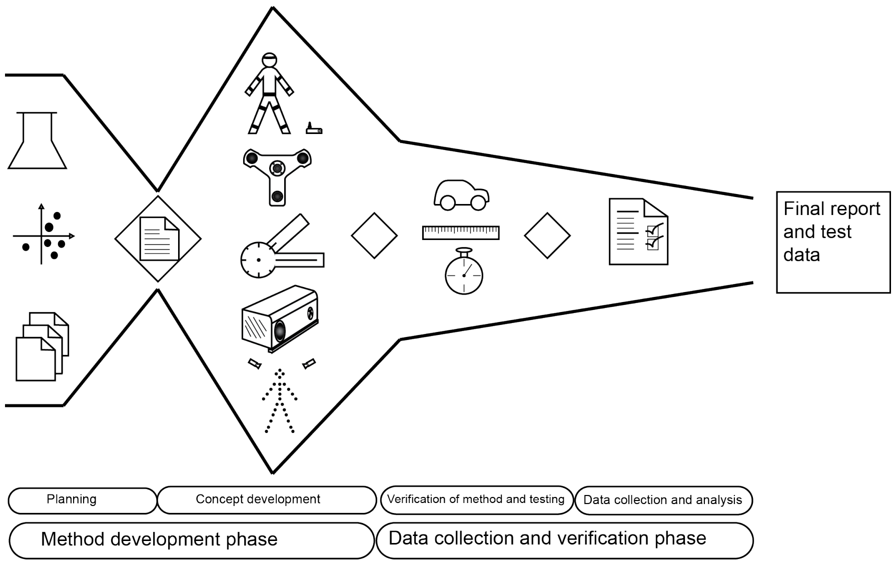


Figure 1.1: Illustration of the modified product development process (Ulrich and Eppinger 2012)

1.3.2 Report structure

The structure this report will follow is that in each chapter all used theory will be presented followed with the application of it and result and discussion will be presented at last.

1.3.3 Time plan

In the beginning of this project a time plan was established. The time plan describes in depth which activities that should be carried out and when. The revised time plan can be found in appendix B.1.

1.4 Prestudy

To initiate this project a prestudy was conducted. In the prestudy a assessment of the stakeholders needs were made, customer needs were collected and several workshops has been carried out.

1.4.1 Stakeholders

One of the first activities performed in the project was a stakeholder assessment, to find possible stakeholders who are affected or affects the outcome of the project. The complete stakeholder identification process can be found in appendix A. In this section the essence of the assessment will be presented. Firstly the project team identified and classified possible stakeholders, this was done with brainstorming and post-it notes. The second step in the stakeholder identification process was to classify them by interest and power. This classification helped the project team to identify the most important stakeholders to focus on throughout the project.

1.4.1.1 Newly identified stakeholders

During the course of the project a handful of new stakeholders occurred. These stakeholders were not identified through the first assessment and appeared during the course of the project. The new stakeholders that the project team have came across is Qualisys, a motion capture company located in Gothenburg. A new branch at Chalmers university of technology, that are interested in the technology that are used in the project. During the project the team has aided the school with technical expertise and also contributed with demonstration of equipment and education for staff members. As the project went further, one of the previously core stakeholders IMMA showed a lot of interest for the technology used, but their lack of power in this project still makes them a second tier stakeholder. Figure 1.2 illustrates the revised power/interest grid constructed from the prestudy A.

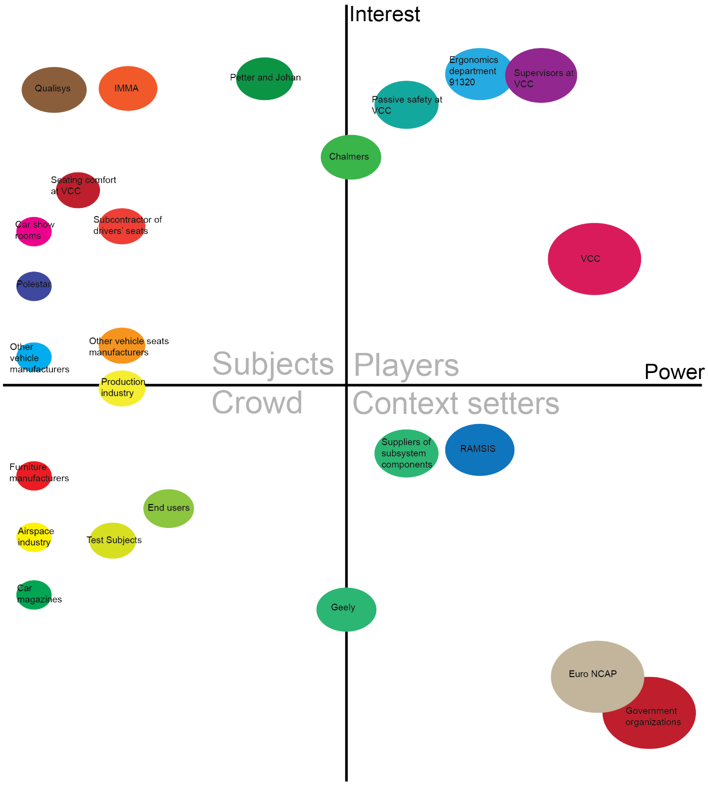


Figure 1.2: Revised power/interest grid

1.4.2 Needs

During the prestudy the customer needs for the method to be developed were collected, the needs collection is part of the qualitative research of this thesis. The needs collecting process was divided into two parts, one part where the project team identified needs based upon the stakeholder statements appendix A and the second part derives from statements collected in two in depth interviews made with two of the key stakeholders. These two interviews were transcribed and statements were extracted from which became statements from interviews appendix A.

The second step in the needs collection process was to categorise the collected statements; both the statements from the stakeholders but also the statements collected in the interviews. As a tool for this the project team utilized a affinity diagram appendix A. When redundant statements had been eliminated and the rest categorised the project team created the needs following Ulrich and Eppingers guidelines appendix A. In the last step the project team divided the needs into three subgroups appendix A. The final list of customer needs divided into three levels can be found in appendixD.1.

1.4.3 The workshops

During the prestudy two workshops were conducted with the people who has several years of experience in the field of vehicle ergonomics. The purpose with the first workshop was to verify and rate the customer needs identified by the project team. This was done since this is the first project in the field of ergonomics that the project team undertakes and they want to be sure of the robustness of the needs. As a second part of the workshop the participants were given coloured dots so they could rate some needs that they thought were of extra importance. Full description and result from workshop one can be found in appendix A. The needs cards used in workshop 1 can be seen in figure 1.3.

As for the second workshop the project team wanted answers on which parameters that were of importance and as an extra step give the participants the possibility to eliminate one of the needs form previous workshop. The tools used for workshop two was four laminated pictures of a seated manikin in a drivers seat and a front view. On these pictures the participants could mark which areas that were of importance for them and give the project team a hint of which parameters the method had to collect. Full description and result from workshop two can be found in appendix A. The mediating tool used in workshop 2 can be seen in figure 1.4.

Figure 1.3: The needs cards used in workshop 1

Data

Needs	Rank
Easy to analyze output data	
The method collects relevant data	
Easy to interpret the continuous data	
The method is compatible with existing input data available at VCC	
The method can collect several different parameters	
The method can collect high frequency data	
The test leader can specify a range for the data collection	
Output data follows VCC standards	
The method provides absolute location of the point of interest in the car	
The method shows difference in drivers posture related to vehicle model	
Participants	

Method

Needs	Rank
The method is applicable to different body types	
The method can provide long term data gathering	
The method is applicable to different vehicle models	
The method gives the test subjects the freedom to be positioned as desired	
The method can collect quantitative data	
The method can be applied during drive	
The method can be applied when the vehicle is stationary	
Accuracy in measurements	
The method can measure the whole body	
The data collection step can be repeated	
Participants	

Output

Needs	Rank
The method provides information about the test subject's position	
The method detects abnormal seating postures	
The method detects causes to shifting driver's posture	
The method can detect the location of the foot	
The method can detect the location of the eyes	
The method can detect the location of the head	
The method can detect the location of the breech	
The method can detect the location of the hip joint	
Participants	

Tests

Needs	Rank
The user finds it easy to setup the testing equipment	
The method conforms to testing time guidelines	
The method serves as a compliment to existing tests	
The method can be applied in customer's cars	
No interference on the test subjects driving skills	
The method can be applied during drive	
The method are compatible to any driving scenario	
The method is easy to learn	
Captured data is compatible with virtual models	
Participants	

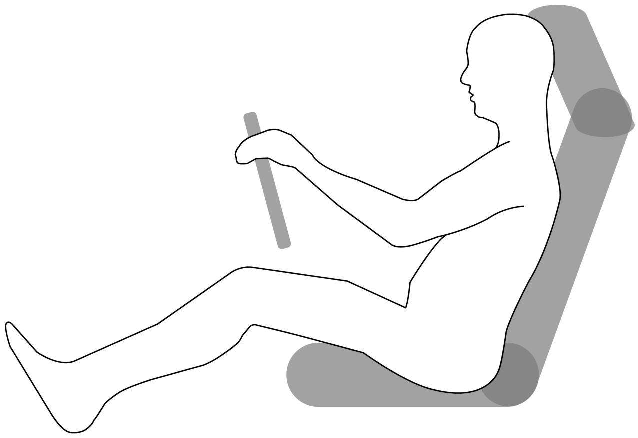


Figure 1.4: Mediating tool used in workshop 2

2
Concept description

In this chapter a presentation of suitable concepts identified as possible data collection tool will be made.

2.1 MVN Awinda

MVN Awinda is a motion capture system developed by a company called Xsens, with headquarters located in Enschede in the Netherlands. Xsens are focused on inertial sensor modules, human motion measurements and 3D character animation. (*Xsens*)

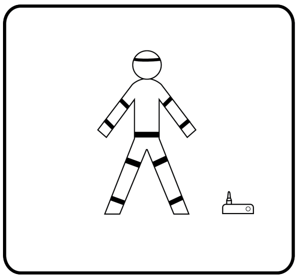


Figure 2.1: Concept sketch of the MVN Awinda system

2.1.1 Hardware

The MVN Awinda system consists of 17 inertial sensors which are attached to the body with Velcro straps. 16 of the sensors are attached to different body parts and the last one can be used as a prop, such as a golf club or sword that is captured by the program. This prop have to be attached to a body segment, so for example something that is put in the hand of the test subject will always be connected to the hand of the subject, even if it is put down. This is because the sensors only measure the relative movement of the sensors after the calibration, not the absolute position. The sensors in the MVN Awinda are all completely wireless, but there are another variation, MVN Link, that uses smaller sensors that are daisy-chained connected to a sender pack located on the back of the test subject. This system can be worn with Velcro straps like the Awinda or with a Lycra suit that the sensors are fastened at. The Lycra suit have dedicated zip-fasteners that the cables and sensors can be fastened in. (*MVN user manual, user guide MVN, MVN BIOMECH, MVN Link, MVN Awinda* 2015)

The inertial sensors consists of four different sensors that determine their position; a gyrometer to measure angular speed (orientation), a magnetometer that measures the magnetic field of the earth (reduces drift in the x-, y-plane), an accelerometer that measures the 3D-acceleration (position), and also to define the normal of the earths curvature(z-axis, to reduce angular drift)(Roetenberg, Luinge, and Slycke 2013), and a barometer to measure the atmospheric pressure. The output from these sensors are combined with a dynamic model, in a Kalman-filter to get the best model for the movement possible.(*MVN user manual, user guide MVN, MVN BIOMECH, MVN Link, MVN Awinda* 2015) The Kalman filter uses the data that are collected by the sensors, and a theoretical model over how the system ought to behave, to make the best prediction of the test subjects movement possible. (Faragher 2012)

2.1.2 Software

The software used with the MVN Awinda is MVN studio. MVN studio defines a bio-mechanical model based on the bio-metrical data that are defined before the calibration phase, and the calibration pose where the position of the sensors are synced with the posture of the test subject. The sensors are then giving the relative movement of each body segment based on the movement of the sensors. (*MVN user manual, user guide MVN, MVN BIOMECH, MVN Link, MVN Awinda* 2015)

2.1.3 Scenario

The Xsens MVN system are currently used for motion capture in animated movies and games, but also in virtual and augumented reality to capture the body movements of the person using the system in real-time. (*Customer cases for Xsens MVN*) The scenario it will be used in this project is, that the system will be used to measure the joint angles of the test person when they are positioned in the seat. This gives the test persons joint angles directly from the model and no further analysis have to be made, other than calculation of mean joint angles.

2.2 FARO Freestyle

FARO Freestyle is a 3D-scanner, developed by FARO that is a 3D measurement technology company. FARO headquarters are located in Lake Mary, Florida. (*FARO company profile*)

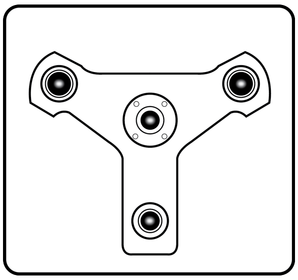


Figure 2.2: Concept sketch of the FARO Freestyle

2.2.1 Hardware

The FARO Freestyle is a structured light scanner. A structured light scanner sends out a IR-pattern that is captured by a camera, and through the offset between the camera and the IR-projector the distance to the object can be determined through triangulation, and the surface geometry can be determined by measuring disturbances in the pattern. (Knicker 2014) To give an increased accuracy to the scanner the Freestyle have two IR-cameras that capture the pattern and triangulates the distance to the object. It also have one RGB-camera to capture the color of the object scanned. (Liscio 2015)

2.2.2 Software

The data that are processed by the FARO Freestyle are exported to FARO Scene, where it can be processed into a point-cloud and from there be exported to a number of different file formats, that then can be used in various CAD-systems. (*Scan & plan with the freestyle3D*)

2.2.3 Scenario

Today the FARO freestyle is used to document objects and rooms in 3D point-clouds (*FARO Freestyle 3D scanner - Efficient handheld 3D laser scanning*). The way it would be used in this project is that the test person will be documented with the FARO freestyle when sitting in the drivers seat, the files would then be analysed to determine the joint angles of the test person.

2.3 Microsoft Kinect

Microsoft Kinect uses a infrared camera and sensors to track the motions of the person using it. It is a motion capture camera developed primarily for the gaming industry. (Weinberg 2015)

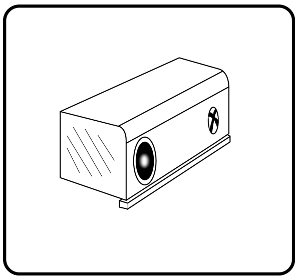


Figure 2.3: Concept sketch of the Microsoft Kinect

2.3.1 Hardware

The Microsoft Kinect is a sensor developed for the gaming platform Xbox One. It uses a similar technique as the FARO Freestyle, a time of flight scanner, which sends out a IR-pattern that is tracked with a monochrome camera and gives information on the distance to objects in front of the Kinect (Choppin and Wheat 2013). The hardware is composed of a RGB-camera, a IR depth sensor, and a Multi-array microphone. (Crawford 2010)

2.3.2 Software

Other companies have developed third-party software for recording using multiple Kinect sensors to increase the accuracy and the field of vision, such as iPi recorder (*Motion capture for the masses*). iPi also have software for transforming the recordings into motion-capture files, and from them get the joint angles of the test subject joint angles (*iPi MoCap Studio* 2016).

2.3.3 Scenario

Microsoft Kinect is mainly used in the gaming industry, to capture motions to control a game. But it could also be used for motion capture, for a much lower price than the conventional motion capture technologies. (*Motion capture for the masses*) In this project a number of Microsoft Kinects have to be used simultaneous to capture the joint angles.

2.4 Qualisys Miqus

Miqus is developed by Qualisys, a motion capture company focused on biomechanical research, sports biomechanics, and medical. Qualisys headquarters are located in Gothenburg Sweden. (*We are Qualisys. The Swedish motion capture company*)

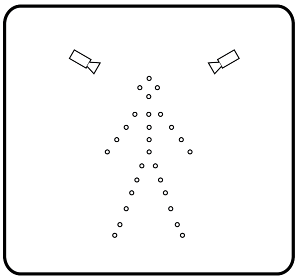


Figure 2.4: Concept sketch of the Qualisys Miqus

2.4.1 Hardware

The Miqus is a optical motion capture camera that is using passive markers placed on the subjects body to locate the motions of the subject (*Miqus* 2015). A optical motion capture system using passive markers, usually consisting of small balls coated with a reflective material that the camera detects. The position of the markers is then decided by triangulation from the camera in software, this means that multiple cameras have to be used. (Kirk, O'Brian, and Forsyth 2005) The Miqus is available in two models, the miqus M1 and the Miqus M2. The Miqus M1 has a sample rate of 250fps, a resolution of 1MP, and a FOV of 58*40°. The Miqus M2 has a sample rate of 340fps, a resolution of 2MP and a FOV of 61*39°. The dimensions for one camera is 14.0*8.7*8.4cm. (*Miqus* 2015)

2.4.2 Software

Qualisys has developed their own software for capturing the data that the Miqus receives, called Qualisys Track Manager (QTM). QTM combines the data that are captured from the cameras and place the markers in a predefined coordinate system. To measure movement in 3D, the cameras have to be calibrated for the area that the motion capture will be performed in. This is done by moving a wand with markers attached, in the space the test will be performed in. The data can then be exported into a number of different programs such as MATLAB.(*Qyalisys Track Manager - QTM*)

2.4.3 Scenario

Qualisys is used in sports analysis to prevent or find injuries, and to improve technique. In engineering it is used to determine position over time. In medical it is used for rehabilitation and in psychology for motion analysis. (*We help people and analyse motion*) To utilize this concept the cameras have to be mounted inside the car and the test subject would be equipped with markers, to acquire the desired information.

2.5 Goniometer

A goniometer is an instrument used to measure the movement in joint angles. Used by physical therapists.(Sears 2016)

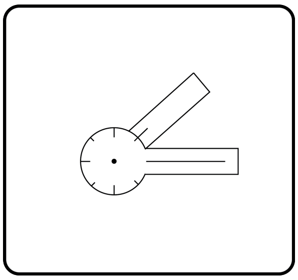


Figure 2.5: Concept sketch of a goinometer

2.5.1 Hardware

The goniometer consists of two arms, that are positioned at specific points of the body, while the center of the goniometer are placed over the center of the joint being measured. Compared to all other concepts this is a very cheap method.

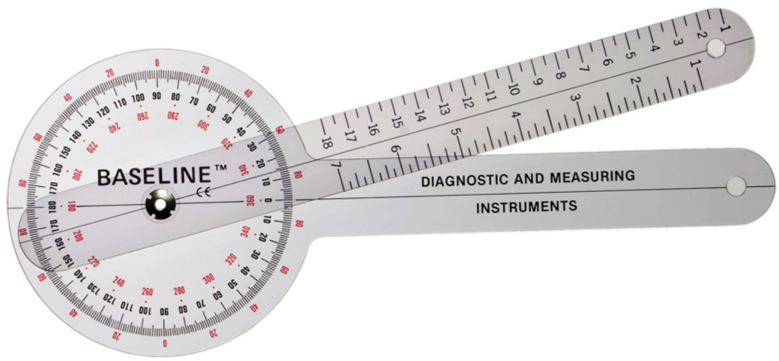


Figure 2.6: A manual goniometer. (*Baseline Plastic goniometers*)

2.5.2 Scenario

A goniometer are used by physiotherapists to measure the range of motion for joints, from one maximum angle to the other(*Measuring flexibility using a goniometer*). Using the goniometer all the test subjects joints have to be measured manually, while they are seated in the driving seat. This would lead to quite inaccurate result due to that all joint angles are not measured at the same time.

2.6 Testing

To acquire knowledge about how well the different concepts would perform in the measuring environment (inside a car) this testing was initialised early in the development process. This testing were done to acquire knowledge about how the concepts worked and not to do a detailed verification of the performance of the different concepts. The technology behind every concept was tested first. The Microsoft Kinect was used to record a test subject performing a reference pose and then performing a set of predefined movements to evaluate how well the motion tracking followed the movement of the test subject.

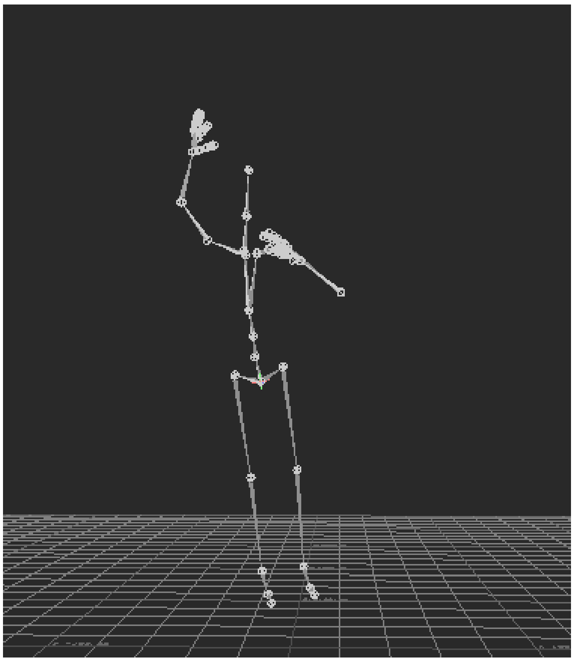


Figure 2.7: Motion capture, with Microsoft Kinect as captured by Motion builder from Autodesk

The MVN Awinda and the Qualisys system were tested in a similar way. With the test subject performing necessary calibrations and then performing a set of predefined movements. The movements was compared to the movements that was captured in the software in real time.
The test of the MVN Awinda was conducted at VCC, with a Awinda system borrowed from the University of Skövde. The Awinda was first tested in a lab, with a test subject walking and performing movements that was given from the test leader. The system was then tested in a stationary vehicle, to evaluate how it would work in the real environment.

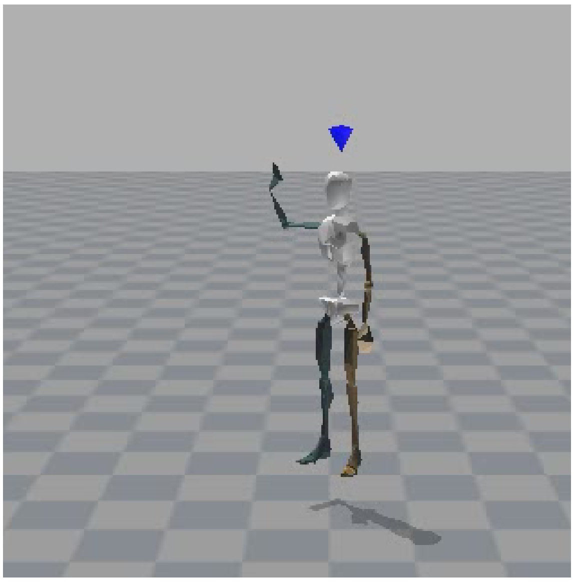


Figure 2.8: Motion capture, with MVN Awinda captured by MVN Studio

Figure 2.9: Test subject with the MVN Awinda equipped.

The test of the Qualisys system was performed at Qualisys facilities in Gothenburg, where a time slot was available for verification. During these tests the test subject was equipped with 23 markers, some markers were also attached to a chair that was used during the session. The test subject was seated in a chair and recorded while doing a number of predefined moves that would simulate driving a car, such as moving the steering wheel, breaking, and changing gear. The Qualisys lab did not have the Miqus cameras installed in the test rig, so instead the verification was done with another of their models, the Oqus. The Oqus have the same basic function as the Miqus, but a higher sample rate and resolution(*Oqus* 2015). The verification was performed primarily to get a overall view of how the technology and how the software works, not the specific performance of the cameras.

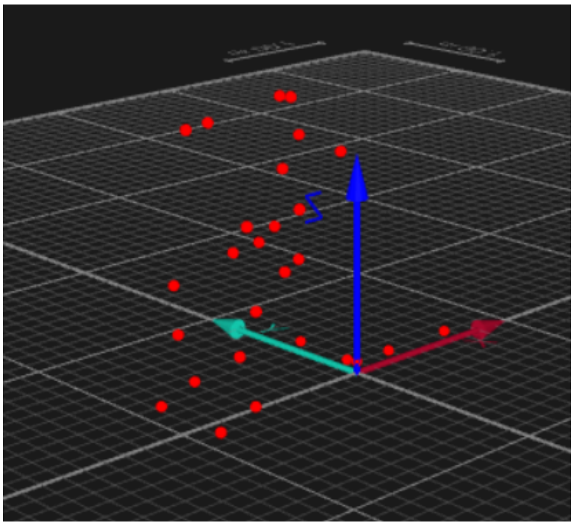


Figure 2.10: Motion capture, with Qualisys Oqus and captured by QTM

Figure 2.11: Test subject with passive markers attached for the Qualisys system

Mock-ups where then created to evaluate how the Miqus camera could be placed in the car and how far away from the drivers seat they could be placed to maximize the FOV.
A rough mock-up was made of a goinometer to get a rough understanding of how the measurements would have to be performed in the testing environment.

Figure 2.12: Mock-up of the Miqus camera placed in a Volvo XC90, to evaluate space and FOV.

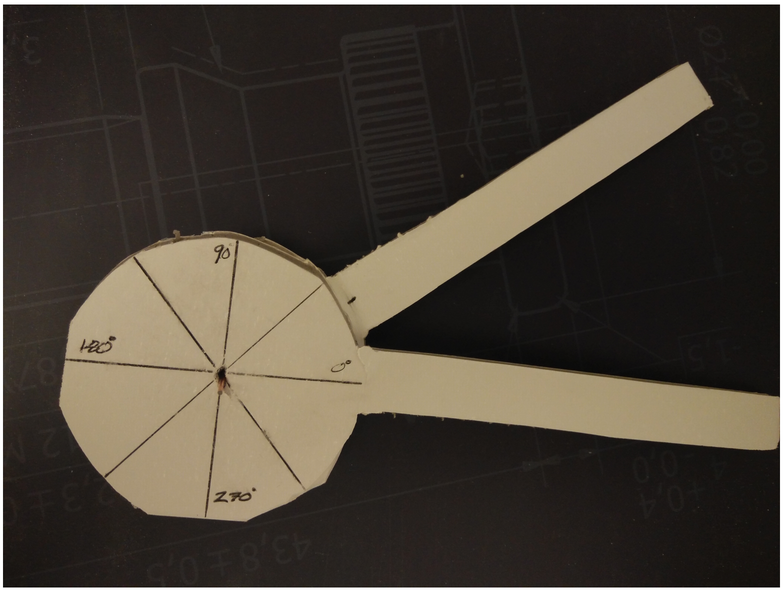


Figure 2.13: Mock-up of a goinometer

3
Concept selection

In this chapter theory, method and result from the concept selection phase will be presented.

3.1 Theory

Utilized theory during concept screening and scoring.

3.1.1 Concept screening

A good way to structure and keep control during an evaluation process is to asses a matrix structure. The matrix is constructed with selection criteria on the y-axis and the concepts for evaluation on the x-axis. By applying a matrix during this stage of the evaluation process will not only give a systematical work flow it will also provide a rational way of rating and discarding low performing concepts. Another benefit with applying a matrix is that it hinders other project members to favor their own ideas or concepts over the other ones. To create the criteria of evaluation a good way is brainstorming. But be aware when brainstorming the criteria of evaluation, they should have some anchoring to the main problem the concepts tries to solve. (Pugh 1991)

When the evaluation criteria has been agreed upon and written down the creation of the matrix begins and evaluation of each concept against each criterion. At the beginning of the evaluation a reference concept is chosen, this is the one all other concepts will be compared against. Then the other concepts are evaluated against each criterion and the reference concept. For example if the criteria is cost and concept A is more expensive then the reference it will get a "-" but if it is cheaper it gets a "+" or cost as much as the reference then it will receive a "0". After all the concepts has been evaluated against each criterion a final score is established. The final score is calculated as the difference between the +'s and -'s and will be in a numerical value. The final score helps too determine which concepts to keep, discard or combine. (Ulrich and Eppinger 2012)

3.1.2 Concept scoring

To narrow down the selection process and distinguish the remaining concepts from each other a weighting and rating matrix can be utilized. The matrix is constructed with concepts to be rated on the x-axis and weighted criterion's on the y-axis. The project team asses each selection criteria with a relative importance in order to assign each concept a score usually between 1-5 or 1-10 on how well they fulfill the criteria. Then the given score is multiplied with the weighting of the criteria and provides a total score. A benefit with weighted criteria is that it helps to rate subjective criteria such as, perceived quality or environmental friendliness. When working with numerical rating of criteria it is always subjected to the judgement and experience of the team members, so another use full way can be to divide the criterion's into three categories, high medium or low.(Pugh 1991)

When selecting the criteria for the selection matrix a good idea is to utilize the customer needs list, to increase the resolution of the scoring secondary and tertiary needs could be used. As suggested by Ulrich and Eppinger a reference concept should be chosen. They also recommend to choose the scale between 1-5 were 3 is same as the reference 1-2 is worse and 4-5 is better, this is done to make the evaluation process less time consuming. As for weighting the criterion's suggestions to use a rating similar to the one proposed in the section above or divide 100 percent among selected criteria. The weighting can be determined by the project team or based upon collected customer needs. (Ulrich and Eppinger 2012)

3.2 Method

How the theory are applied for concept screening and concept scoring.

3.2.1 Concept screening

The first step in concept screening for the project were to choose which concepts to rate against each other. The project team choose the five original concepts which were evaluated during the concept development phase and added a minor change to one of them, an extra sensor was added to the Kinect concept. This concept is only theoretical and has not been evaluated during the concept development phase, but the main idea behind it is that the accuracy of the system will increase. The project team brought a total of six concepts for screening against a reference concept (Ulrich and Eppinger 2012). The reference concept, the goniometer were chosen because it is the only system that is known, out of the concepts chosen, to work in a vehicle. The drawbacks with this concept is that it is very primitive, inaccurate and time consuming to use, plus it is the only concept that is analogue.

Determining the selection criteria were done during a brainstorming session. A total of nine individual criterion's were created. The chosen criterion's are the ones the project team identified as the best suited ones to cover as big part of the whole project as possible in as few criteria as possible. The main areas in which the criteria have anchoring in usability of the system, cost, and the impact of the system on the vehicle and driver.

The concepts evaluated during the concept development phase are complete systems, the combination option were discarded during the screening. This is due to limitations in time and limited benefits, decision was made to not combine any systems at this point of the project. The result from the screening can be found in appendix E.1. The main outcome is that two concepts were discarded during this activity, the ones using the Kinect sensor.

3.2.2 Concept scoring

The project team entered the scoring phase with four concepts, the reference and three other. Except for the reference the other concepts brought to the scoring were MVN Awinda, Faro freestyle and Qualisys Miqus. As for the selection criteria the project team utilized the full customer needs list appendix D.1 divided into three types of needs (Pugh 1991), must, would and should. In the first scoring session the must needs appendix F.1 were applied, in the second scoring the should needs appendix F.2, and in the third scoring the would needs appendixF.3. The most important session was the first, this is because the must needs is the most important and if the concept doesn't score good here it will have no chance to perform at the minimum level of the requirements. As for the weighting of the criteria the project team utilized the rated customer needs cards from 1.4.3, and used a 100 percent scale for each type of needs.

During the first scoring of the concepts the needs in the must section were applied. The project team used a grading scale between 1-5 to rank each concept against the criteria, as a reference the concept goinometer was used and first graded in consensus by the project team (Ulrich and Eppinger 2012). During the first scoring with the "must" criterion's the faro freestyle concept was eliminated and the full result can be found in appendix F.1. As for the second scoring the two remaining concepts were the MVN awinda and the Qualisys Miqus system, the goinometer was kept as reference. The result from the second scoring was in i favor for the MVN awinada concept, full result can be found in appendix F.2. The final scoring was done to increase the resolution but also to give the project team the extra confidence that they made the right decision. The scoring was carried out with the goinometer as reference and the two remaining concepts from scoring two were kept, full result from scoring three can be found in appendix F.3. As a result from all three scoring the MVN awinda came out as a winner and this concept went to the next development stage.

3.3 Discussion

In this section discussion about how the project team approached and carried out the concept selection will be held.

3.3.1 Reference concept

As suggested by Ulrich and Eppinger (2012) a reference concept should always be chosen and used as a benchmark in the evaluation of the other concepts. The reference concept doesn't need to be static and can be changed from screening to screening or scoring to scoring. In this project the project team chooses to keep the same concept as reference during both screening and scoring. Why this choice was made to keep the goinometer as reference and only perform one screening was because this was the only concept that the project team knew would give the joint angles and the only concept that was analogue. As for the other concepts the project team knew that they would produce some uncertainties regarding measurement accuracy and before the measurement error was known they were not suitable as references. Another issue was also that the project team didn't knew if the other concepts would stay stable during a longer period of drive.

3.3.2 Selection criteria

Here the selection criteria for both the screening and scoring will be discussed. They will be divided into the different headings, criteria for concept screening and criteria for concept scoring.

3.3.2.1 Criteria for concept screening

The selection criteria for the concept screening were created as suggested by Pugh (1991). As mentioned above the project team wanted to keep the selection criteria as few as possible to not make the initial selection phase too complicated. As for the strategy to select a few main areas and anchoring the criteria to the areas was a good approach. Not only did it make the whole screening processes easier but also helped the project team make a just evaluation between the reference concepts and the one subjected for rating. Another benefit with choosing a few main areas to connect the criteria to is that the project team knew what was expected of the final concept.

3.3.2.2 Criteria for concept scoring

The selection criteria applied in the concept scoring origins from the customers needs list appendix D.1. By utilizing the needs that the project team collected in the prestudy the validity of choosing the right concept for further development increases. The robustness of the selection criteria has been verified in 1.4.3 and therefore the project team felt confident with the previous statement. The weighting of the criteria was done as proposed by (Ulrich and Eppinger 2012) and by utilizing the result from 1.4.3 the importance of each criteria has been captured correctly. Furthermore a second review of the weighting has been done with the supervisors after the concept selection process in order to assure the validity of the result.

3.3.3 Concept screening

The concept screening activity was used as an elimination step in the concept selection process in this project. Why the team didn't utilize the activity to combine low ranking concepts as suggested by (Ulrich and Eppinger 2012) is because the complexity of the concepts. Since the concepts consist of basically full systems as described in chapter 2 with special hardware and software, integration between them would be difficult. The project team didn't have the time or know how to do this so the option of combination of concepts was discarded.

3.3.4 Concept scoring

The activity concept scoring is one of if not the most important activity performed in this project. This is where the tool for data collection and the back bone in the method to be developed is chosen. To ensure that the scoring was done with as high resolution as possible the project team did as suggested by (Ulrich and Eppinger 2012). By increasing the detail level of the scoring the project team felt comfortable with the result.

In the the must needs section 64 percent of the weighting was divided among 6 out of 16 needs. This distribution of the weight put a lot of extra emphasis on these needs, make them extra important since they would decide which concepts that would have made it to the next session.

All concepts scored fairly high, of these 6 needs except for two. The most important criteria *Give joint angles/segment position* where the Faro Freestyle received score of two. The project team felt secure in their grading here since this concept did not have the possibility to provide either individual segments, such as and isolated leg or arm or joint angles.

As for the need *the concept can be applied during drive*, at this need the final concept does not perform as rated in the scoring. After the final concept had been chosen the project team identified a huge problem, the final concept can not be applied during drive. This is due to technical limitations in the hardware that was discovered after the final concept had been selected. Regardless if the winning concept the MWN Awinda received a lower score, even as low as one it would not change the outcome of the first scoring session. If the score at this criterion was lowered to one the final score would become 3,34 which is the same as the second best scoring concept.

In the two last scoring sessions the final concept MWN Awinda came out as clear winner every time. The benefit that the MWN Awinda had in the should session origins from that the systems is easier to set up and the data interpretation of output data is more manageable to handle.

Lastly the project team would like to mention that the only thing that changed from the second to the third session are the criteria and weight. The two concepts were kept the same to help the team to justify that the right concept was chosen for further development.

4

Concept Development and Verification

In this chapter the further work with the concept MVN Awinda is described and a verification of the systems robustness is made, through image analysis.

4.1 Introduction to the problem

As described in chapter 2 the MWN Awinda concept keeps track of x- and y-axis with the help of magnetometer and the z-axis with the magnetic field of the earth. This turned out to become a problem when the system is applied in an environment with stronger magnetic fields then the earths. This problem was undiscovered by the project team during the concept evaluation but as the teams knowledge grew the problem became apparent. In order to minimize the impact of the magnetic disturbances on the MWN Awinda that is generated from the vehicles chassis and embedded electrical systems a simple factorial design experiment was constructed.

4.1.1 Design of experiment

The problem identified in previous section is that the MVN Awinda system looses it's accuracy and starts to drift, see fig.4.1 when subjected to a magnetic field. To minimize the impact from the magnetic fields in the vehicle the project team established a factorial design experiment.
In a factorial design experiment the first step is to identify which factors who contributes to the specific problem. According to Bergman and Klefsjö (2010) can a cause and effect diagram be a good approach to identify interesting factors. After a set of factors has been established two levels of a high and a low value are chosen for each factor, when a factor is at a low value it is expressed with a "-" and when high a "+". The number of chosen factors determines how many different tests the experiment will include and is described with the formula 2^n, were n is equal to the amount of factors, one testing session is called a run. At each run the different factors are either high or low until all possible combinations has been evaluated, see figure 4.2. When executing design of the experiment the order of the runs should be randomized in order to avoid interference from other factors. From these test it is then possible to calculate the effects from each factor, the effect is how much specific factor affects the final result. The main effect for a factor is calculated as the difference between the result when the factor was high and low. Factors can

Figure 4.1: Illustration of a drifting system

also interact with each other and create an effect, as for example lets take a sick patient. The patient is first treated with penicillin and nothing happens, then the patient gets a chemotherapy and still nothing happens. But with chemotherapy and penicillin in combination the patient get cured, that is the effect of interaction between factors. (Bergman and Klefsjö 2010)

Picture 4.3 illustrates a factorial design experiment with the factors A, B and C the first number in the circle represent the run and the y_x is the result from that run. To calculate the effect for factor A the equation $(y_2 - y_1)$ is used. The arithmetic average for factor A is calculated as $1/4((y_2 - y_1) + (y_4 - y_3) + (y_6 - y_5) + (y_8 - y_7))$. As for calculation of interaction effects the design matrix can be utilized see figure 4.2. If another row is added for the interaction between AxB the low respective high levels of this interaction will be factor A's level multiplied with factors B's at a certain run. AxB level at run 1 would become a "+" since "-" x "-" = "+" and so on. Depending on if the interaction factor is high or low at the run it will affect the value of the y_x. If the interaction between AxB is calculated with the formula above it will look like this $1/4(y_1 - y_2 - y_3 + y_4 + y_5 - y_6 - y_7 + y_8)$. (Bergman and Klefsjö 2010)

Run no	Factor		
	A	B	C
1	-	-	-
2	+	-	-
3	-	+	-
4	+	+	-
5	-	-	+
6	+	-	+
7	-	+	+
8	+	+	+

Figure 4.2: Illustartion of a design matrix for a full factorial design experiment inspired by (Bergman and Klefsjö 2010)

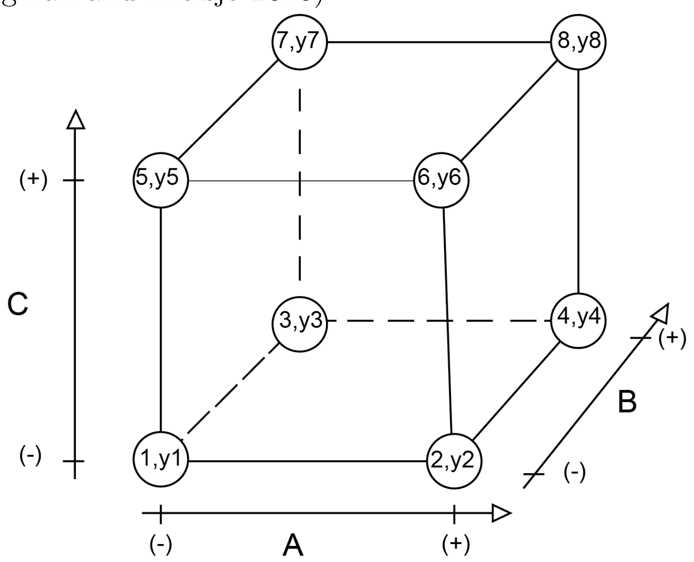


Figure 4.3: Illustartion of the design matrix as a cube inspired by (Bergman and Klefsjö 2010)

4.1.2 The MVN Awinda experiment

The identified problem with the MVN Awinda concept is that it will start to drift when exposed to magnetic fields, since the concept have to work during drive the project team tried to identify which factors that could extend the time before the system starts to drift. The first factor *sensor warm up* was identified from the manual (*MVN user manual, user guide MVN, MVN BIOMECH, MVN Link, MVN Awinda* 2015), as mentioned in chapter 2 the system applies a Kalman filter in order to calculate the sensors position. By adding the extra warm up time the prediction is that the filters will stay stable for a longer period of time. As for the second factor *calibrate outside the car* which was identified through brainstorming of the project team, the reasoning was that by placing the base station outside the vehicle interference of magnetic fields would decrease. The last factor *number of turns* was also identified with brainstorming. The reasoning is that since the system drifts in the x and y direction the amount of turns on a track might make the system to drift faster. The high and low values for each factor is summarized in figure 4.1.

Table 4.1: High and low values for the factors in the MVN Awinda experiment

Values for the factors		
Factor	-	+
Sensor warm up	0 [s]	30 [s]
Calibrate outside the car	No	Yes
Number of turns	Straight road	Curvy road

The experiment was performed in three different vehicle models in order to see if there was any difference regarding type, the tested vehicles were a Volvo V40, V60 and a XC90. All experiments were performed at the same route and when the factor number of turns was high the vehicle drove a course with many roundabouts and one extra lap in each roundabout was done, when the factor was low the vehicle took a course with a straight road. During the test the MVN Awinda system was applied to the driver and the test leader was responsible for keeping track of the system until he noticed a drift in the software. When the test leader noticed the drift the time on a stop watch that was started at the beginning of the run was written down and that is the y-value in this experiment.

4.1.3 Result from the MVN Awinda experiment

The main outcome from these three experiments was that the factor that extended the time before the system started to drift in a vehcile was *sensor warm up*. The main effect from this factor was 67,5 in the XC90, 70,75 in the V60 and 31,5 in the V40. The factor with a negative effect on the time the system could be applied during drive was *number of turns* were the main effect was -26,5 in the XC90, 23,75 in the V60 and -25 in the V40. The factor *calibrate outside the car*, had a minor effect in the XC90 and the V60, but a bigger effect in the V40. This could be due to the smaller body of the V40 which shields the signal from the sensors and gives a more unstable system. The complete design matrices can be found in G.1, G.2 and G.3

4.2 Image verification of the system

Image analysis was performed to evaluate how well the MVN model match the real body posture of the test subject. Two different verifications were made. One verification with the verification subjects (VS) seated in a vehicle, with the Awinda system equipped, to give an estimation of how good the Awinda system represents the posture of a test subject in a vehicle. One other verification was made, with the VS standing in a open room and sitting in a chair. This verification was done to get more exact data on how well the Awinda system represents the posture of the VS.

4.2.1 Subjective verification

The first verification was done with five VS. Each VS was equipped with the Awinda, some markers to mark the joints of the verification subject, and then seated in a vehicle. A recording was started in MVN studio, and a picture was taken with a camera from outside the vehicle at the same time as a marker was set in the MVN recording, to assure that the model and the picture are synced in time. A snip was then taken in the MVN studio file from the same viewpoint as the camera had been placed. The snip was then placed over the picture using Microsoft PowerPoint. The location of the hip-joint was used as a reference point for placement, to get a comparison between the real body posture of the VS, and the MVN model. This verification method are inspired by the verification used by Kirk, O'Brian, and Forsyth (2005). This result was entirely subjective, based on how well the manikin represented the picture of the verification subject. The manikin was seen as a good representation of the overall body posture of the test subject, but some individual joint angles was not seen as good enough. To further investigate this problem the verification in 4.2.2 was done.

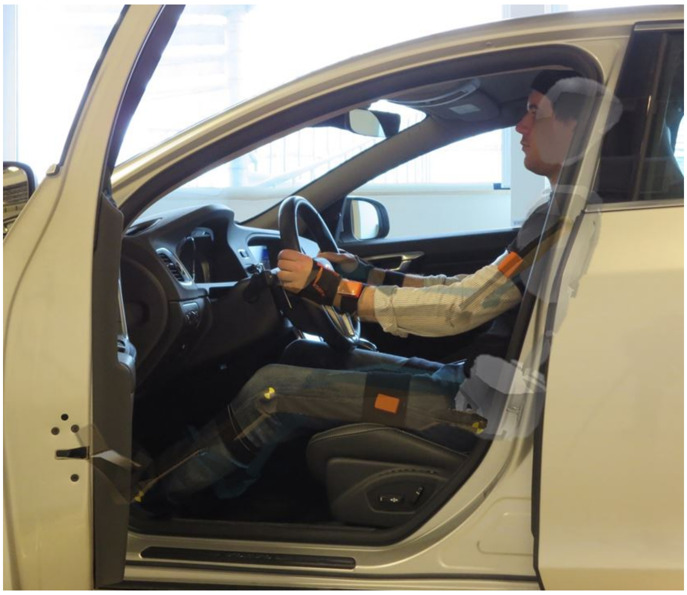


Figure 4.4: The MVN mannequin placed on top of a picture of the test subject, for verification.

Five of these verifications was made with five different persons. To assure that size or body posture of the test subject would not affect the result of the verification. These verification pictures can be found in Appendix. H.1

4.2.2 Image measurements

The image measurements were performed outside the car, with five verification subjects with different body height see 4.2 , to get a more exact result that could be used to evaluate how exact each joint angle are in MVN studio. To do this a picture was taken and a marker was set as in the previous verification. Analysis was then made using a image analysis software.

Table 4.2: length of the verification subjects

	Length
VS1	184
VS2	174
VS3	190
VS4	196
VS5	170

4.2.2.1 software description

For the image analysis used to verify the Awinda system, ImageJ was used. ImageJ is a JAVA based image analysis program (*ImageJ, Image processing and analysis in Java*). To verify that the measurements in ImageJ are accurate, some measurements was done in pictures were the angles are known, see fig.H.5.

4.2.2.2 Performing the measurements

The VS was asked to perform a T-pose and then to sit in a wooden chair, with picture taken and a marker placed in the MVN Studio recording, at each step, to sync the recording with the picture. Measurements was then performed using ImageJ, as can be seen in fig.4.5 and fig.4.6. The measurement error between these figure are then calculated. The full table of measurements and figures can be found in appendix. H.2 To assure that the picture was taken at the same angle as the viewpoint in MVN studio the origin was set at the point of the camera. This was achieved by performing the calibration at a marked point, which place the origin of the coordinate-system, and then placing the camera at that point.

4.2.2.3 Analysis of the verification

The result from this second verification was compared with the range of joint angles, measured in a car identified by Hanson, Sperling, and Akselsson (2006) for the sitting position and Barter, Emanuel, and Truett (1957) for the standing T-pose, to get an

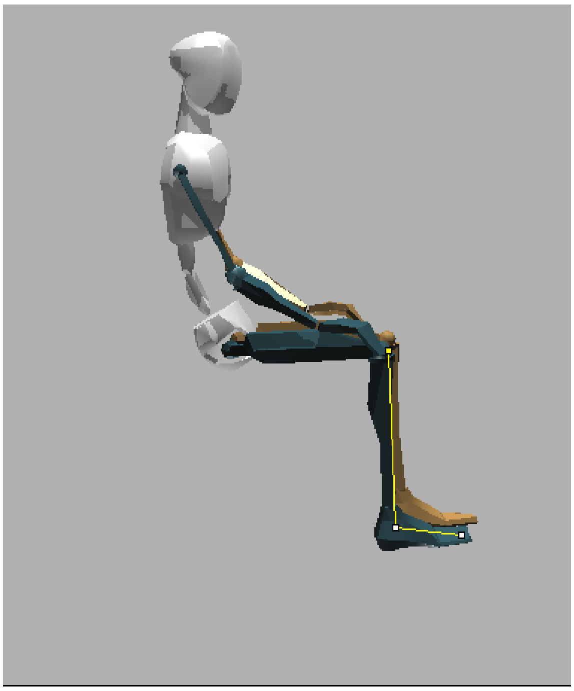


Figure 4.5: Measurement done in the MVN model on the test subjects ankle.

Figure 4.6: Measurement done in the picture of the test subject.

indication of how much the error would affect the result of the measurements. As can be seen in table 4.3 the error is much larger in the seated position, than in the standing position.

Table 4.3: Table showing the minimum, maximum, and mean measured errors and their percentage in the motion range identified by Hanson, Sperling, and Akselsson (2006) and Barter, Emanuel, and Truett (1957)

T-pose	**Max[°]**	**Min[°]**	**Mean[°]**	**Motion range(MR)[°]**	**Max error in % of MR**	**Min error in % of MR**	**Mean error in % of MR**
L-Shoulder	8,3	1,9	5,6	-			
R-Shoulder	5,78	0,3	2,4	-			
L-elbow	6,6	0,7	2,8	122	5,4	0,6	2,3
R-elbow	6,2	1,7	4,3	122	5,1	1,4	3,5
L-knee	4,4	0,3	1,6	73	6,0	0,4	2,1
R-knee	2,7	0,3	1,2	73	3,7	0,4	1,7
Spine	1,8	0,04	0,9	-	-	-	-
Sitting							
Hip	9,2	1,9	6,3	31	29,7	6,1	20,3
Knee	19,3	1,9	9,7	48	40,2	4,0	20,1
Elbow	11,8	0	6,5	65	18,2	0,0	10,1
Spine	15,7	0,7	7,9	-	-	-	-
Upper-spine	8,1	0,2	4,7	-	-	-	-
Lower-spine	16,5	0	5,8	-	-	-	-
Ankle	12,3	1	5,8	21	58,6	4,8	27,8

4.3 Discussion

In this section discussion about the MVN Awinda experiment will be held but also for the image verification of the accuracy of the MVN Awinda.

4.3.1 Selecting the factors

As for the identification of the factors for the MVN Awinda experiment the project team consulted the manual provided with the system. The manual provided information about if the system feels unstable a longer calibration time might solve the problem, from this information the first factor was identified. It is known that the systems accuracy starts to drift when exposed to magnetic fields the project team started to think of what is creating these fields in and around a vehicle. The first thought was all cables and electrical systems but also the body of the vehicle. After some discussion the factor *calibrate outside the car* was discovered.

As mentioned by Bergman and Klefsjö (2010) a good way to identify factors is to apply a cause and effect diagram, this was not done by the project team. Instead brainstorming and discussion about the matter was done.

4.3.2 Factors with high and low effect

The factor that had the highest positive effect in all three experiments were *Sensor warm up*. The result was expected since this factor origins from the (*MVN user manual, user guide MVN, MVN BIOMECH, MVN Link, MVN Awinda* 2015) and it advices the user to take some extra time, standing still after the calibration, in order to give the Kalman filters a chance to collect good data in order to stay stable for a longer time. Why the effect in a V40 is almost 50% lower then in the XC90 and V60 might depend on the size of the cars. Since the driver has less space in the

V40 and the test subject might be subjected to the magnetic field from the electrical wiring inside the vehicle easier then in the other models. As a result from less space in the drivers seat and closer contact with the magnetic fields a lower effect for the factor *sensor warm up* is obtained from the V40. The last factor *Calibrate outside the car* was only important in the V40 where it had a positive effect, in the other two vehicles the factor did not have an noticeable effect. This could be due to the smaller body of the V40 shielding the signals from the sensors to the receiver.

The other interesting effect is *number of turns*, in the XC90 and the V40 it is negative but in the V60 it is positive. The project team is not completely sure why the effects turn out like this for the factor. But the project team would like to imply that a high value on this factor will decrease the stability of the system. To be complete confident about this statement the team would like top perform one or two more experiments to see if this was just a coincidence that the effect became positive in the V60.

4.3.3 Verification

The subjective verification shown in 4.4 was performed to get an initial feeling of how well the MVN mannequin represents the body posture of the test subject.

The verification using ImageJ was done to get hard data on how well the system performed. The error was bigger in the seated position as can be seen in appendix. H.2, this is most likely due to movement of the sensors when the test subject sits down in the chair. Especially the pelvis sensor had a tendency to move when the test subject was seated in such a steep angle between the hip and the spine(the test subject was seated in a 90° angle to make it easy to measure in ImageJ).

The first verification subject had experience using the Awinda system, and may therefore been more aware of the movement of the pelvis sensor and deliberately have countered this. The first verification subject also had the Velcro straps with the sensors fastened directly on the skin (wearing shorts) to minimise the movement of the straps during seating. The other test participants were wearing pants with the Velcro straps fastened over, this may have resulted in that the pants moved the Velcro straps when the verification subject sat down in the chair. As a result the measurement errors of the first test subject are relatively even for the T-pose and the sitting verification, with the larges errors being 6.3° and 6.8° respectively. All the results from the verification can be seen in H.2

Some uncertainty came from the accuracy that joint positions was identified by the project team. Markers were placed where the joints was found on the VS to help the image analysis, but these markers could like the Velcro straps, have moved between the different postures and added to the error in the seated position.

The verification could have been done using the data from MVN studio directly, but the project group choose not to, because it was very hard to see the exact rotation of the joint in ImageJ and compare that to the measurements that was done in MVN. So a 2D representation was done with the manikin instead.

The biggest errors in the seated verification test are to big to be said to give a good representation of the joint angles of the VS, but all the visual representations that was done inside the car are a fairly well representation of the body posture of the VS. This could mean that the position of the joints were identified incorrectly, or that that the sensors moved more when the VS was seated at a steeper angle, or a combination of the two.

5

Method development and validation

In this chapter theory, development approach and usage of the developed method capture drivers posture will be presented and discussed.

5.1 Introduction

To be able to improve the DH-models with a better representation of the drivers posture data needs to be collected from real people when they drive a vehicle. To collect this data and to validate the method a study with n=45 participants will be performed utilizing the developed method capture drivers posture. As a validation tool to ensure the quality and evaluate the method a questionnaire is constructed and handed to the participants at the end of each study. This chapter contains identified limitations and prerequisites, applied theory and the development process of the method capture drivers posture.

5.1.1 Limitations and prerequisites for developing the method capture drivers posture

Chapter 4 describes the work when the project team wanted to see how the impact of magnetic disturbance generated from the vehicle could be minimized. No real solution to the problem was identified, but if the warm up time after calibration was increased the system stayed stable a bit longer when subjected to magnetic fields. Unfortunately the findings in chapter 4 didn't improve the system enough for it to be suitable for data collection during drive. A limitation before developing the method of capture drivers posture is that no data collection with the MVN Awinda system can be done during drive. Another limitation to consider when developing the method capture drivers posture is that only the joint angles will be captured with the MVN Awinda system. The last limitation derives from chapter 4 as well, due to the lack of robustness in the system uncertainties regarding the output data is fairly high and therefore the final result from the method will be seen as uncertain.

A prerequisite on the outcome of the method is that in the collected data differences between drivers posture in a low and a high vehicle can be identified. To be able to collect this type of data from the studys two different vehicles were used; a Volvo V40 and a XC60.

5.2 Theory

Description of theory behind the questionnaire design.

5.2.1 Questionnaire design

To collect quantitative data from the studys a questionnaire was constructed. As suggested by McQuarrie (2012) a questionnaire should follow some basic rules. The first set of guidelines gives advice on the layout of the questionnaire and the second set gives guidance on how to phrase the questions and thirdly how to structure the answering categories.

When constructing a questionnaire it is important to explain the value of completing the questionnaire for the participants, usually this is done with a short but informative introduction in the beginning. Next step is to try to keep the survey as short as possible, this is due to economic incentives and if the task sees overwhelming to the participants it is more likely that they will not complete the survey. Other useful guidelines is to keep a red thread throughout the form, try to put the classification questions at the end and keep a professional layout if time and budget allows. (McQuarrie 2012).

Creating the questions is as important as having a good layout. First of is to phrase the questions as simple as possible, a good rule of thumb is to adapt the language to a eight-graders reading level. Secondly be as specific as possible in the phrasing, even if the question gets a bit longer it will provide less room for misinterpretation from the participant. Open-ended questions is of great value when conducting a qualitative research but as for a quantitative survey they will demand too much from the participant and instead of answering the question the test subject might include biases which makes comparisons between results harder, but in the end of the survey it can be good to include one or two open-ended questions.

As for answering categories in the questionnaire suggested by McQuarrie (2012), a ranking scale is preferred over a rating scale. Rating scales is good to utilize if the number of items to compare is less than five otherwise the task quickly can become too challenging. Another aspect of choosing a rating scale over a ranking is when analysing the ranking data, it has a tendency to become too time consuming. (McQuarrie 2012)

5.3 Developing the method capture drivers posture

Here development of the data collection method capture drivers posture will be described.

5.3.1 Learnings and limitations

In the previous chapter 4 a description of the instability problem with the MVN Awinda system and the possible solution to this is explored. Unfortunately these new findings changes the condition that data collection shall be done in a moving vehicle and adds a new limitation to the method capture drivers posture. The new approach that the project team has to work with is how to replicate the driving condition as good as possible. After a brainstorming session in the project team and discussion with the supervisors for the project consensus was reached, that the best solution is to let the test subjects drive the vehicles first and then apply the system and gather data of joint angles.

5.3.2 Questionnaire creation and development of the four stages in the method capture drivers posture

A good way to structure and describe the method capture drivers posture is to divide it into four different stages. Figure 5.1 illustrates the different stages.

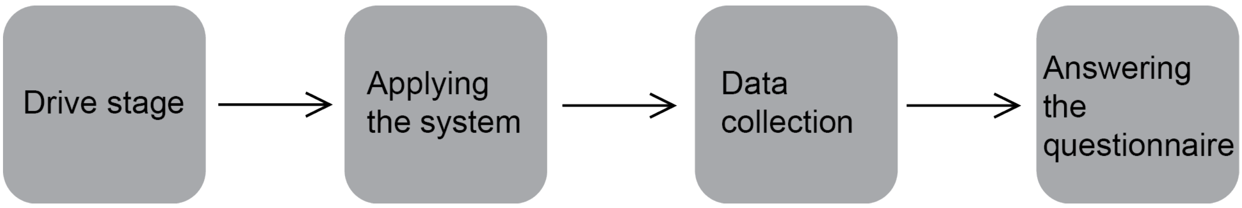


Figure 5.1: The four stages in the method capture drivers posture

5.3.2.1 Questionnaire creation

To be able to evaluate the method and assure that the test subjects assumed a good driving position a questionnaire was created with respect to the suggested guidelines by McQuarrie (2012). First the project team identified four major areas that the questionnaire should address, theses areas are *evaluation of the method*, *validation of the test subjects driving position*, *limitations of the vehicle* and *perception of the MVN Awinda system*. The full questionnaire with all questions can be found in appendix I.1.

To each area a set of questions were created, each area contained two or three questions each, however emphasis was placed on the *evaluation of the method* and *perception of the MVN Awinda system* who contains three questions each. The final question of the questionnaire was an open-ended where the test subject was allowed to leave a comment of any kind as suggested by (McQuarrie 2012). For ranking scale the project team selected a 1-10 scale commonly used at similar studys. This was done since the test subjects would recognize the scale and give a more accurate answer.

5.3.2.2 The drive stage

The first stage of the capture drivers posture is to let the test subjects drive the two different vehicles and adjust the driver seat in a comfortable position. To give the test subject time to assume a good driving position and get them in to a driving mode a course of five minutes per vehicle were set. To give the test subject the opportunity to assume a comfortable driving position the driver seats in both cars were set to a starting position of furthest back, no tilt and at the lowest height. Before the test subject starts to drive the initial position of the motors in the seat is recorded from the CAN bus slot in the vehicle with Volvo cars software.

5.3.2.3 Applying the system

After the drive stage it was time to apply the MVN Awinda system to the test subject. To perform this stage the project team allocated a testing facility with parking slots right outside. After the system was applied a calibration was performed inside the testing facility and the factor warm up time was applied.

5.3.2.4 Data collection

After the MVN Awinda system was applied and calibrated the test subject was shown outside to the two vehicles and seated inside them. The subject was asked to assume their previous driving position as good as they can and then a sample of 15 seconds was recorded in the capturing software for the MVN Awinda system. Also a reference photo was taken from the side with a stationary GoPro camera. This was done for both vehicles. After the recording session the test subject was lead inside and the driver seats new position was measured and the seats were restored to their starting position.

5.3.2.5 Answering the questionnaire

As final stage the system was removed from the test subject and a short introduction to the questionnaire was given. In the introduction the purpose and the ranking scale was explained for the test subject.

5.4 Performing the method capture drivers posture

In this section description of performing the study capture drivers posture will be explained.

5.4.1 Acquiring test subjects

The test subjects for the study were summoned from Volvo cars internal list of volunteers for studys. A total of n=45 subjects participated in the studys where the distribution consisted of 14 short people, 16 normal and 15 tall. A doodle poll with available time slots was created and an invitation was emailed. Due to low response rate the project team had to add an extra session of three days to gather the right amount participant.

5.4.2 Time allocation and execution

The time allocated for each run in the study was set to 40 minutes, in the later stage the project team managed to lower the time to 30 minutes for each session. Since the method will become a compliment to an existing seat position method at Volvo cars the final time allocation will be 15 minutes where 10 minutes is for applying the system and 5 is for the data collection step.

The study drivers posture was performed as described in previous section 5.3.2. Regarding needed equipment the method can utilize existing equipment that is used in the seat positioning method, the only extra equipment needed is the MVN Awinda system and a computer with the capturing software. Since the seating position of the driver is changed when the test subject was driving a low versus a high vehicle, the driver was positioned closer to the floor in a low vehicle then in a high. The two vehicles utilized in the study drivers posture were one low and one high, a V40 and a XC60. But in further studys the seat position study will dictate which vehicle to use. Picture 5.2 describes the interaction between the seat position study and the study drivers posture.

5.5 Result and validation from the questionnaire

The result from the study capture drivers posture will be presented and discussed in chapter 6. In this section validation of the result from the questionnaire will be presented.

5.5.1 Result from the questionnaire

The result from the questionnaire can be found in appendix J.1 for the short population, J.2 for the normal and J.3 for the tall. The interesting questions for this

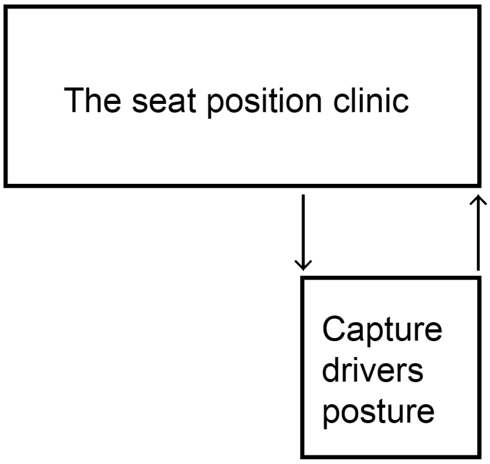


Figure 5.2: Interaction between the seat position study and drivers posture

section is the ones regarding the areas of *evaluation of the method* and *perception of the MVN Awinda system.*

5.5.1.1 Results regarding evaluation of the method

The questions concerning the method evaluation are *How would you rate your overall experience of this study*, *Did you find the test course easy to drive* and *Was the test time allocated to the test drive sufficient for you to assume your perfect driving position*, the questions will be referred to as 1,2 and 3 in the order as presented in the text. Figure 5.1 present the average score for each question.

Table 5.1: Summary of the score for questions regarding evaluation of the method

Question	Average
1	9.3
2	9.5
3	8.6

5.5.1.2 Results regarding perception of the MVN Awinda system

The questions of interest in the perception of the MVN Awinda system are *Did the measurement equipment affect your driving position*, *Do you feel uncomfortable wearing the measurement equipment* and *Did you feel uncomfortable when the measurement equipment was applied.* Same as in previous section the questions will be referred to as 1, 2 and 3 in the order as presented in the text. Figure 5.2 presents the average score for each question.

Table 5.2: Summary of the score for questions regarding perception of the MVN Awinda system

Question	Average
1	9.4
2	8.9
3	9.4

5.6 Discussion

In this section discussion about the design of the questionnaire and the validation of the developed method capture drivers posture will be presented.

5.6.1 The questionnaire

The first step in the creation of the questionnaire was to identify which areas should be examined. By identifying these main areas and structure the survey after them, it gives the questionnaire the red thread as suggested by McQuarrie (2012). The red thread is followed except for the first question which asks about the overall experience of the study and it belongs to the group evaluation of the method area. This was done at purpose by the project team. Even that the question belongs to a certain area the project team thought it was so general and good start question.

As for the phrasing of the questions the project team tried to keep the language as simple as possible and avoiding technical terms. This choice was made due to the test subjects different background and experience level in order to avoid misinterpretation of the question.

By applying a commonly used rating scale see figure 5.3, the project team believe that it became easier for the test subjects to give a more accurate answer than they would done if not that scale was utilized. As suggested by McQuarrie (2012) when utilizing a ranked scale instead of rating between questions analysing the output data gets much easier. The scale is simple and ranging from 1-10 but for each number it has an explanation of how the impact of each score is. The project team still would like to say that the answers from the test subjects might not be as accurate as it would, since the observations were made when the test subjects who work in departments where this scale is commonly used in their daily job made a more restrictive rating then the other subjects did. A possible explanation to the observation might be that the technology used for data collection is new and exiting which may influence the test subject to become more generous in their rating. Over all the project team got the impression that the test subjects found the study to be innovative and fun which might explain the high overall experience score.

1	2	3	4	5	6	7	8	9	10
Very bad		Bad		Ok		Good		Very good	

Figure 5.3: The rating scale utilized for the questionnaire in the method capture drivers posture

5.6.2 Evaluation of the method

Judging from the score for the three questions regarding the evaluation of the method is that the project team can make some conclusions. Regarding the overall experience of the study which got a 9,3 in average score out of 10 that all test subjects were pleased with the study. The same conclusion can be drawn for the choice of the test course, it is good to know that the test subjects found it easy to drive and that it didn't generated any extra stress and was suitable regarding the test subjects driving skills. If the test course would have been too demanding to drive for the participants maybe the focus would have been more on the driving section in the study than it would have been on finding a suitable driving position.

The lowest scoring question was the last question which asks the test subject if the right amount of time was allocated for them to assume their perfect driving position. Except for the first question that is about the general satisfaction of the study the project team would like to state that this is the most important question in the whole survey. Initially the data collection in the method would occur during drive, due to limitations in the technology this part had to be modified and changed to replicate a driving scenario. The score on this question helps to determine the quality of the captured data. If this question would have received a low score, the quality of the gathered data may not be accurate enough to represent the drivers posture in a driving scenario. Even though this question was the lowest scoring one with a 8,6 out of 10 the project team still feels confident that most of the test subjects actually had the time to assume their most comfortable driving position in both the vehicles.

5.6.3 Perception of the MVN Awinda system

Since the technology used for data gathering in this study are a new technology, therefore it is important to know how the test subjects perceived it and if it caused any limitations in the study. One main concern was that the sensors would become a issue when the subject was sitting in the driver seat and could affect the test subjects driving position. The test subjects doesn't believe the Awinda system affects their driving position, since the system received a 9,4 out of 10 the project team can make the conclusion that this type of data gathering tool can be suitable for this type of studys.

The system consists of 16 individual IMU-sensors strapped to the body with Velcro straps. When the verification tests were done with the system, it was avoided to have fabric between the straps and the body, instead of long legged pants shorts and t-shirt were used in the test. The project team have also tried out the system with fabric between the body and the strap and it feels a bit awkward but after some time that feeling is gone. Why the test subjects ranked this question as the lowest can be because it is the first time they try the system and the data collection time wasn't long enough for them to "forget" about the system. Over all the score is high and gives a good indication to the project team that this type of equipment can be used for this type of data gathering with subjects that are unfamiliar with the system.

The last question about how the systems is applied was the one that the project team had greatest concerns with. Since the system consists of Velcro straps that are applied to the legs and arms, body contact will occur between the test leader and subject. The initial thought was that some of the subjects didn't expect this type of contact and would have declined when the project team informed them about that some body contact will occur. Luckily this was not the case, as seen by the ranking of the question 9,4 of 10 but also from comments made by the subjects when they were informed in the beginning of the study. The project team thinks of two reasons why the test subjects didn't have any problem with this. Firstly the test subjects who signs up for this type of studies did it on their own initiative and they know what they have signed up for, another reason can be how the subjects perceive the approach from the test leader. If the test leader would act as the test subject felt uncomfortable and insecure with the task it would affected the mind set of the test subject but instead if the test leader have some experience with the system and acts in a professional the application of the system gets de-dramatized.

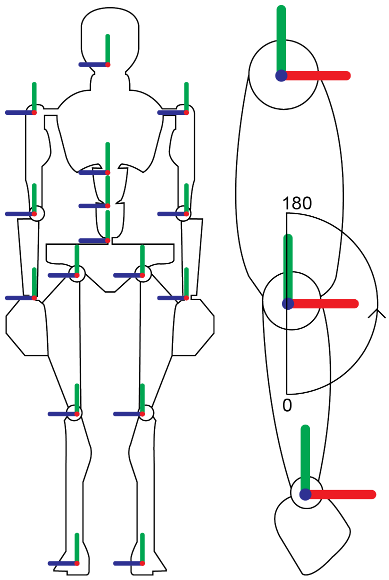
6

Verification of the method

Here the measurements from the clinics will be presented. A visual exemplification will be done to represent how the body posture representation differ between test subjects with different body shapes. Graphs will be shown to illustrate how the measured joint angles differs between test subjects and the low (V40) and high (XC60) vehicle. Data from the settings of the seat will not be presented. The graphs presented in this chapter are chosen to illustrate the difference in body posture, between different seating height and different test subjects. Therefore the joints chosen for representation are the joints that show the biggest difference between test subjects with different body shapes. A presentation of the measurements in each vehicle will be done, and then a comparison will be made between the different vehicles. This is done to show that the method are capable to show differences in posture between high and low vehicle and between different test subjects. The expected result are that the taller test subjects will have a less bent knee and hip due to longer legs, and that the smaller V40 will have less bent knee and hip joints, than the higher XC60.

In fig.6.1 the MVN-manikin can be seen standing in the 'N-pose' which is the reference for the measurements made. Each joint have a coordinate system as described in the picture. In the 'N-pose' every joint angle are zero around every coordinate axis, if a body segment are moved the system will give the corresponding joint angle difference from the starting angle. If for example the test subject lift their right arm straight ahead, there will be a angle rotation around the Z-axis(blue in the picture), and the joint angle will increase. A bigger joint angle means that the joint have rotated to the front of the body in reference to the starting position.

Figure 6.1: N-pose with coordinate systems and arm with angle indicator



6.1 Measurements made in the V40

A clear difference can be seen in the seating position of the short test subject seen in fig.6.2 and the short heavy test subject seen in fig.6.3. The test subject in fig.6.2 are seated close to the steering wheel and have a steep angle in the hip joint and in the knees. The test subject presented in fig.6.3 have a almost straight hip- and knee-angle, and are more laid back in the seat than the test subject in fig.6.2. The seating position of these two test subject are very different although they are almost the same height.

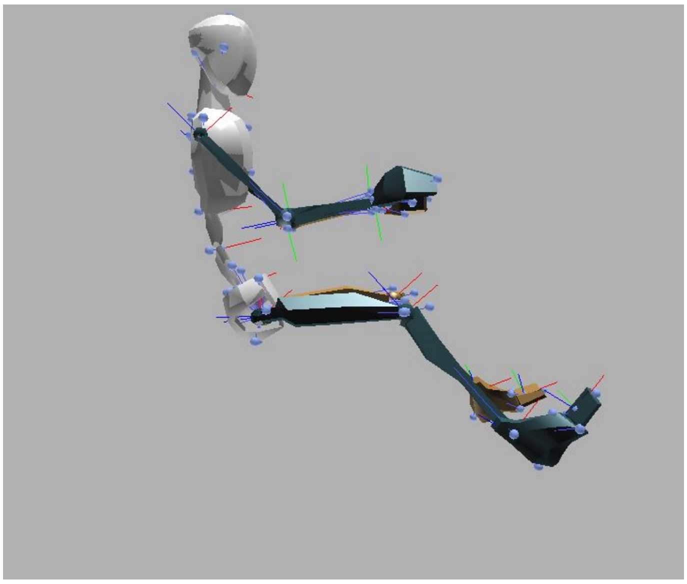


Figure 6.2: Short test subject positioned in the V40

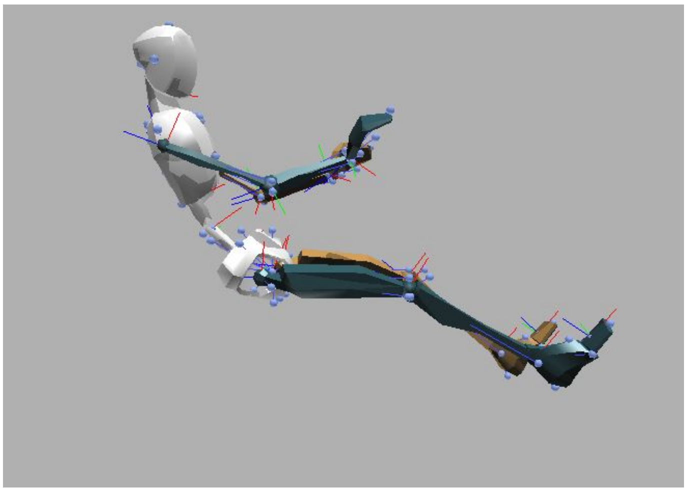


Figure 6.3: Short heavy test subject positioned in the V40

The mid ranged test subject, seen in fig.6.4 have a steeper hip- and knee joint angle than the test subject in fig.6.3, but not as steep as the test subject in fig.6.2. The mid range test subject have a lower seating position, further away from the steering wheel than the short test subjects.

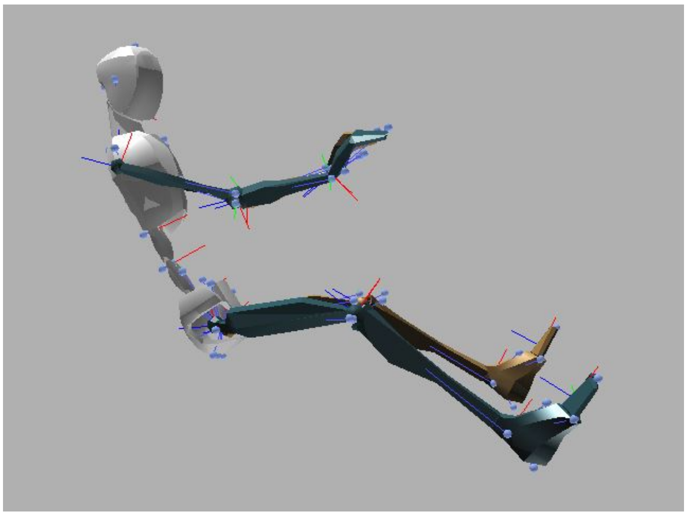


Figure 6.4: Mid range test subject positioned in the V40

The tall test subject, seen in fig.6.5, has a very low seating position compared to the others, which gives a quite steep hip- and knee angle.

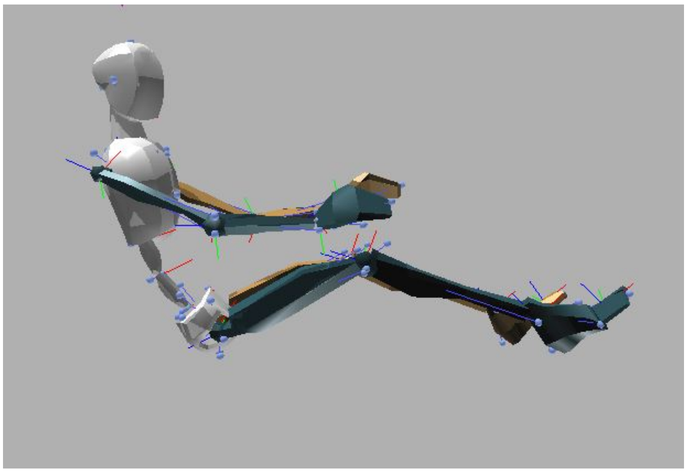


Figure 6.5: Tall test subject positioned in the V40

The graph 6.6 show a very low R^2-value, this means that the data is not showing any significant correlation between the joint angle of the knee and the body height of the test subjects.

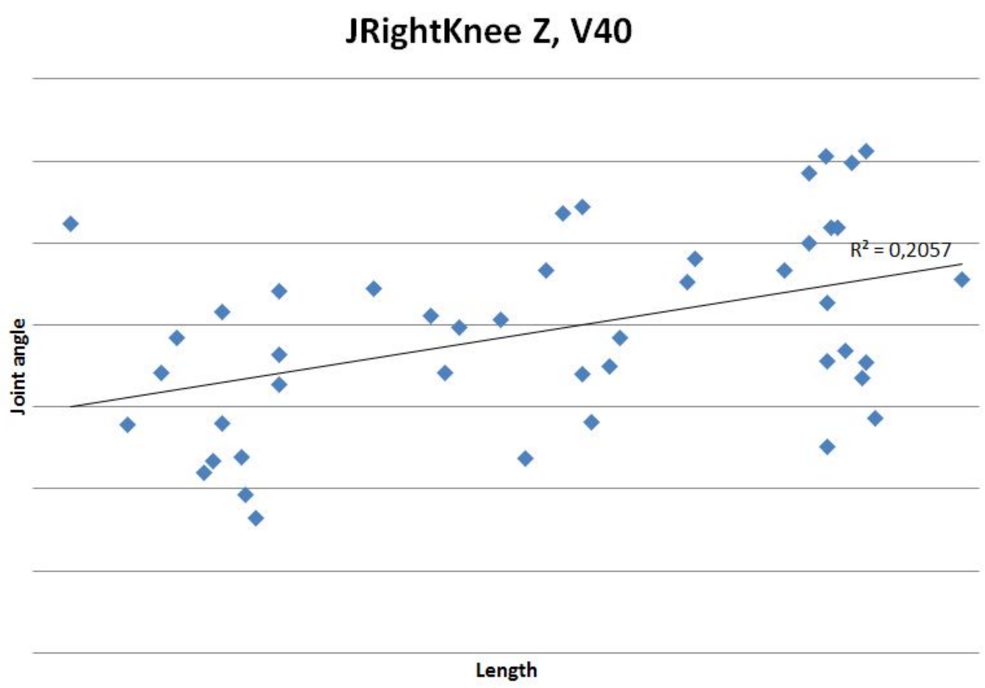


Figure 6.6: Graph over the joint angles of the right knee, measured in the V40

In the graph over the hip joint-angle, fig.6.7

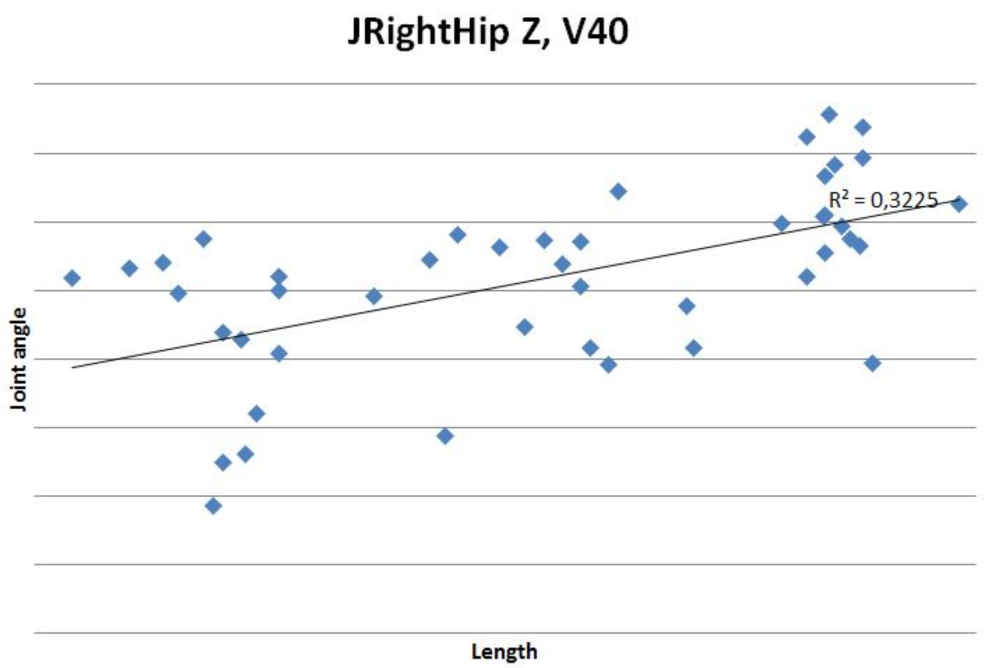


Figure 6.7: Graph over the joint angle of the right hip, measured in the V40

6.8 shows the joint angle of the shoulder in the V40. The graph shows a slight increase of the joint angle for the test subjects that are taller. Due to the R^2-value no correlation can be said to occur.

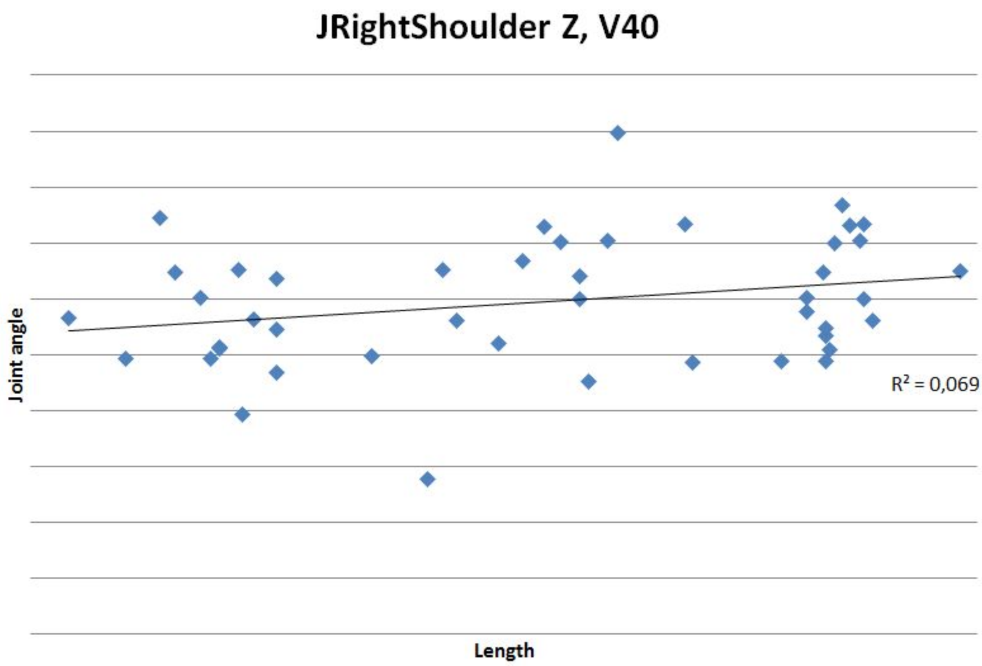
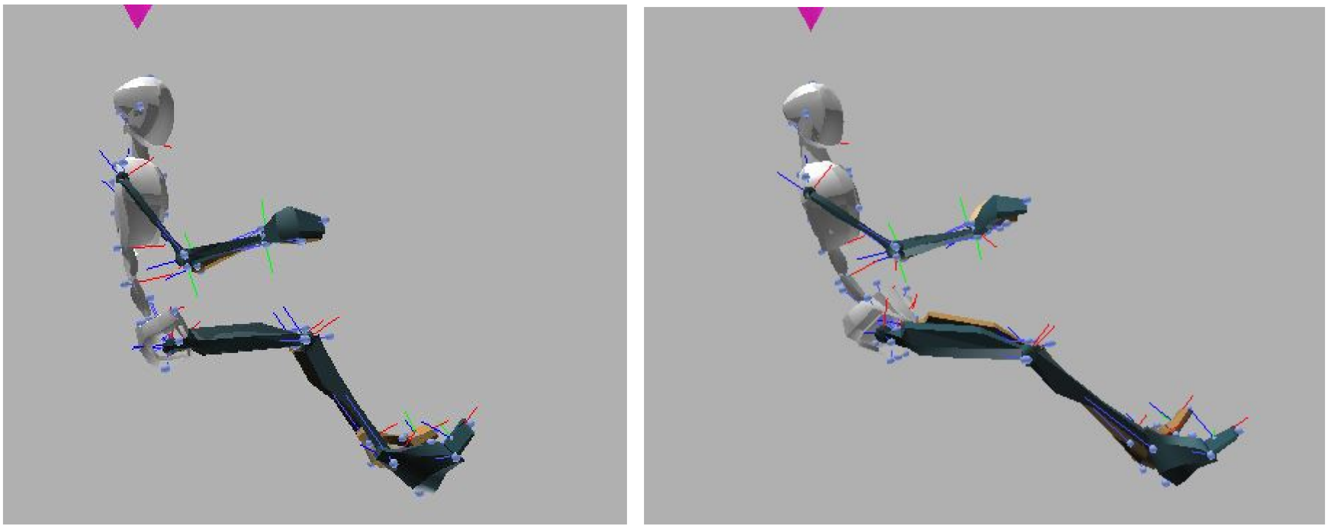


Figure 6.8: Graph over the joint angle in the right shoulder

6.2 Measurements made in the XC60

The short test subject, see fig.6.9,

Figure 6.9: Short test subject positioned in the XC60 and short heavy test subject positioned in the XC60



The mid range test subject seen in fig.6.10 have a smaller angle at the knee in the XC60 which means a straighter leg.

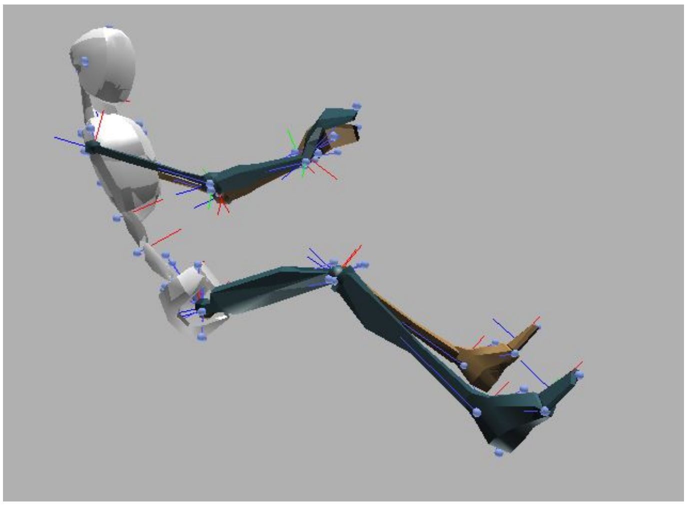


Figure 6.10: Mid range test subject positioned in the XC60

In fig.6.11 the tall test subject can be seen positioned in the XC60.

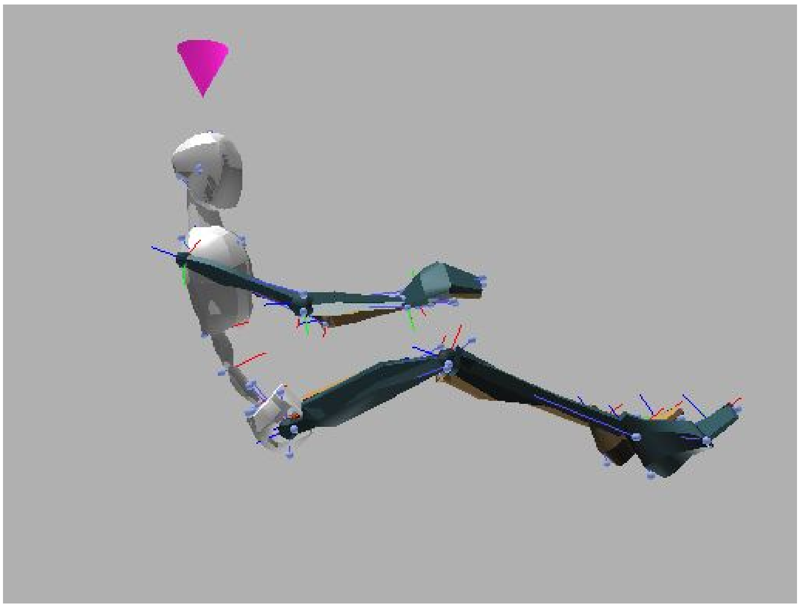


Figure 6.11: Tall test subject positioned in the XC60

The graph over the knee-angle of the test subjects in the XC60, show just like in the V40 that the R^2-value are too low to show any correlation between body height and knee-angle.

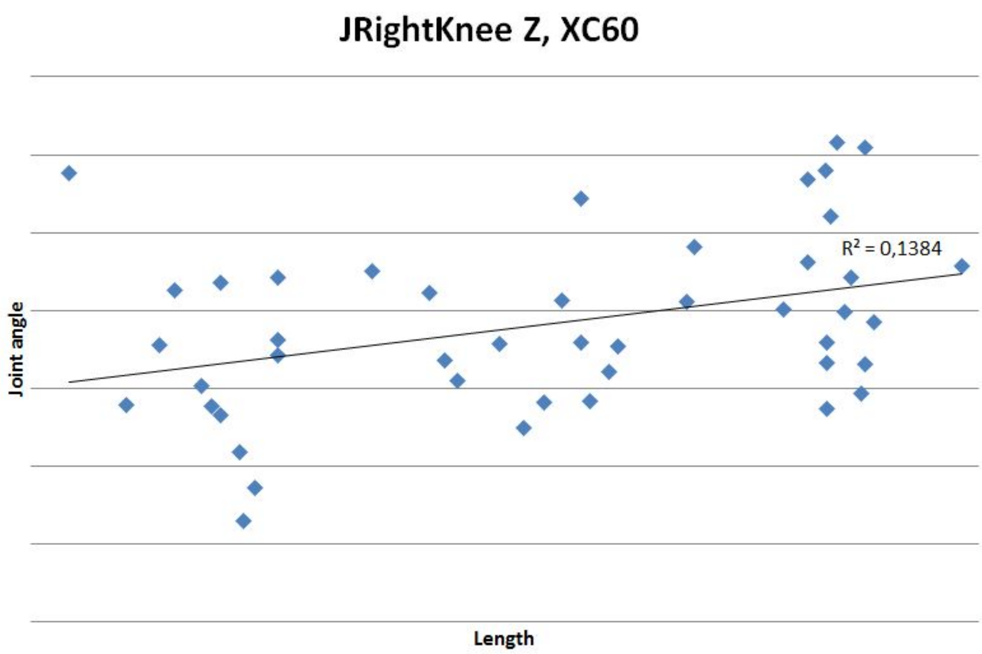


Figure 6.12: Graph over the joint angle of the right knee, measured in the XC60

The graph in 6.14 show the joint angle of the test subjects in the XC60. The correlation are bigger than for the knee-joint but the R^2-value are still too low to show any correlation between body height and hip-angle.

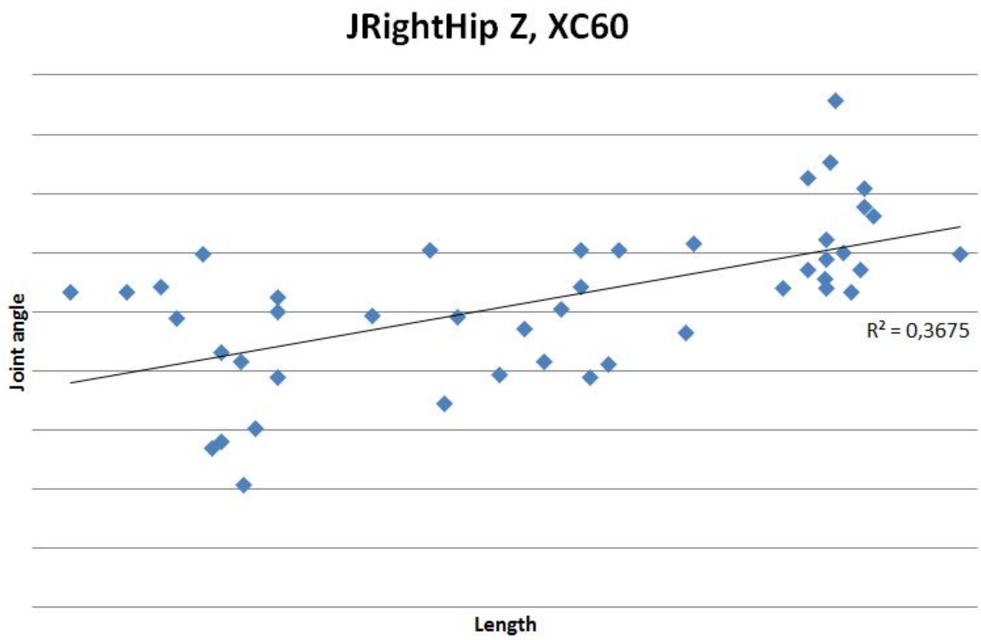


Figure 6.13: Graph over the joint angle of the right hip, measured in the XC60

Figure 6.14: Graph over the joint angle of the right shoulder

6.3 Comparison between the posture in the V40 and the XC60

The graph in 6.15 show the correlation between the knee angle in the XC60 compared to the knee angle in the V40. The graph shows that the test subjects have a slightly more bent knee in the V40 compared to the XC60.

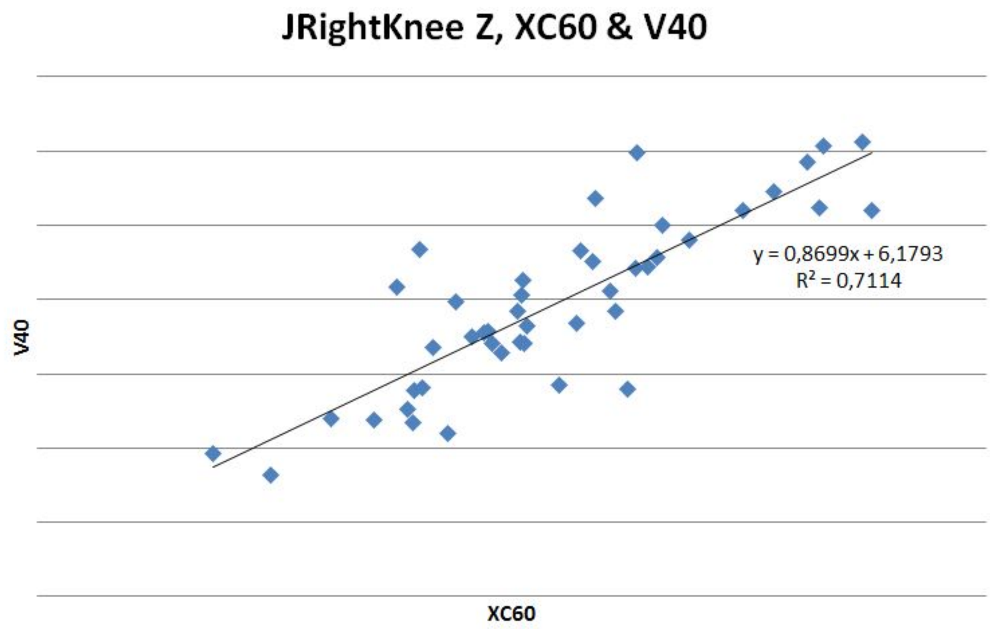


Figure 6.15: The knee joint angle plotted for the XC60 compared to the V40

The graph in 6.16 show the correlation between the hip angle in the XC60 compared to the hip angle in the V40. Like the knee angle it shows a slightly more bent joint angle in the V40 compared to the XC60.

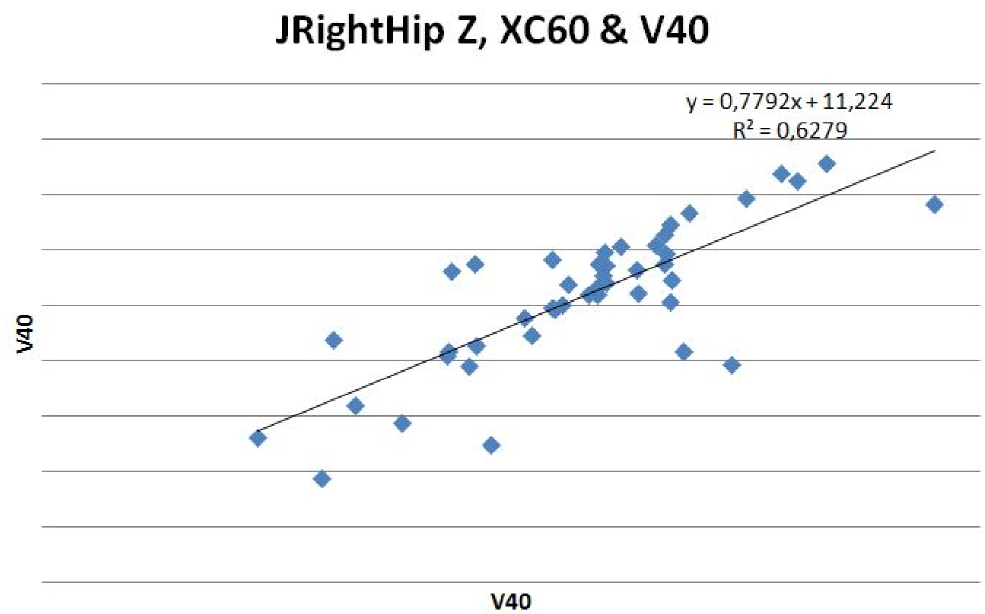


Figure 6.16: The hip joint angle plotted for the XC60 compared to the V40

The graph in 6.17 show the correlation of the joint angle in the shoulder in the

XC60 compared to the joint angle in the V40. The R^2-value are too low to show a correlation between the joint angle in the two vehicles.

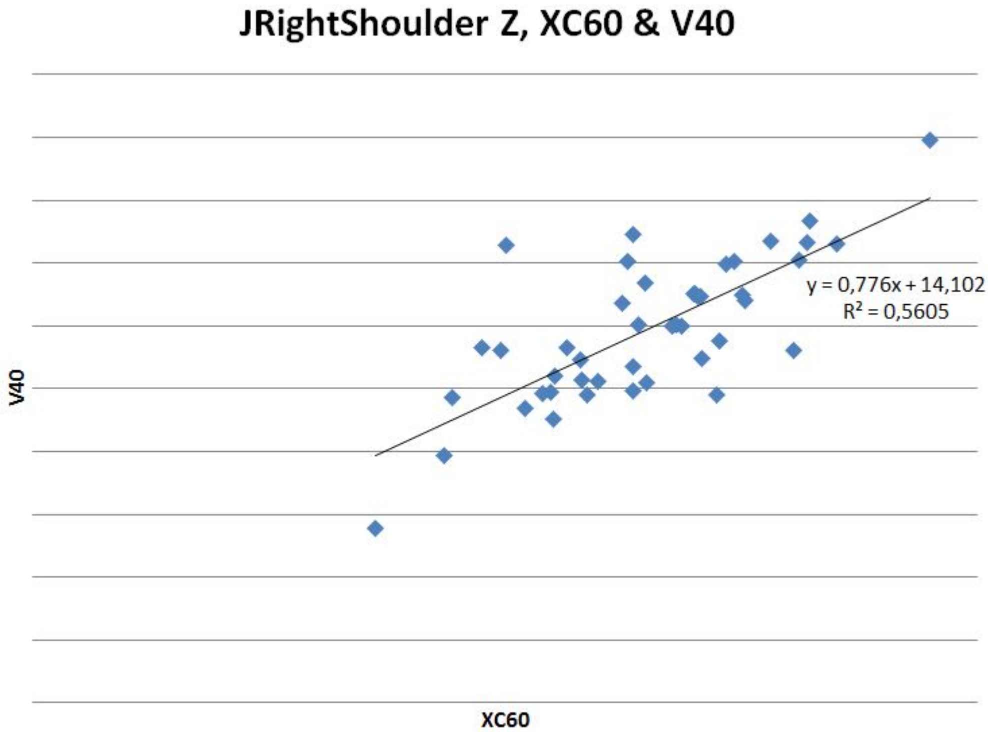


Figure 6.17: The shoulder joint angle plotted for the XC60 compared to the V40

Fig. 6.18 show that the measured ankle joint angle of the test subjects are bigger in the V40 than in the XC60.

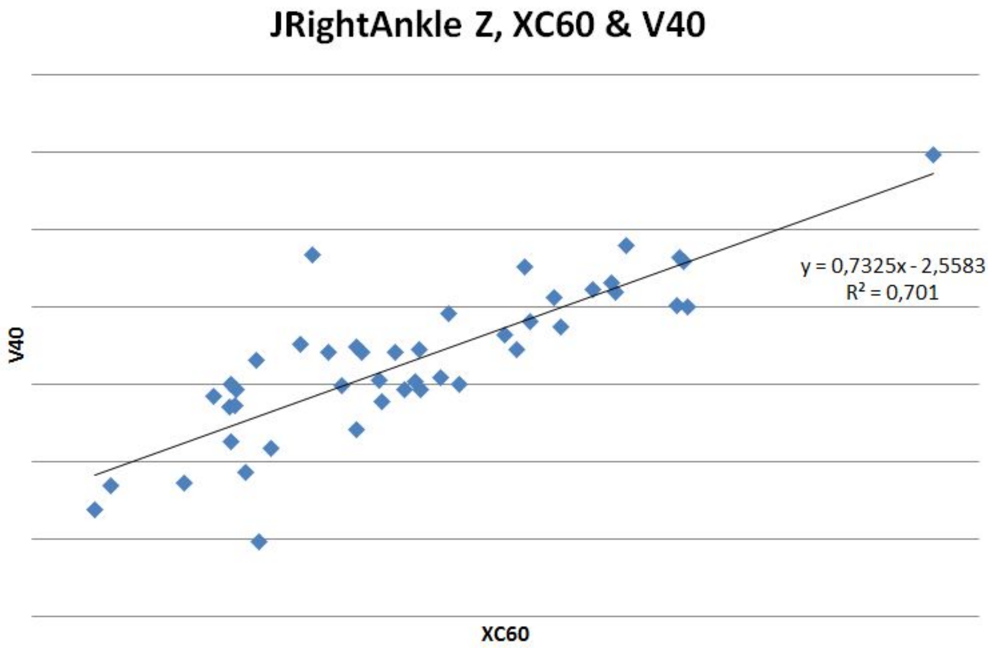


Figure 6.18: The joint angle of the ankle plotted for the XC60 compared to the V40

6.4 Discussion

The measurements presented in 6.1 and 6.2 show that the chosen method is capable to detect the joint angles of the test subjects, and show a difference in posture for test subjects with different body height. The data does not show a clear correlation between the body height of the test subjects, this is probably due to the adjustment possibilities of the vehicles. The data presented in 6.3 shows that the method is capable of showing a difference in the posture of test subjects in different vehicles, with different seating height. In the beginning of the chapter suggested theory indicates that the test subject would have a straighter leg and therefore a lower knee joint angle in the V40 than in the XC60. The results from the data collection displays that the test subjects have the lowest and highest knee angle in the XC60. This is believed to occur due to the greater adjustment area in the XC60 compared to the V40.

7

Further development, recommendations, final result and final discussion

Here further development to improve the method and use of the MVN Awinda, recommendations will be given on how Volvo car can continue with this system and other application areas, and a final discussion will be presented.

7.1 Further development

Here further development and alternative uses with the method and the MVN Awinda system are presented. There are many possible applications for the MVN Awinda at Volvo car and other industries. The motion capture function could be used for ergonomics analysis in many different scenarios for example ingress and egress(*analysis of vehicle ingress and egress*). The system could also be used to simulate many different scenarios in real-time (*Reliability, you value it when you don't have it*), examples of this is walk through of production facilities, simulation of break down scenarios with users and as a visualization tool for evaluation of concepts.

7.1.1 Creation of a new world

After the concept selection of the MVN Awinda system discussion of different areas of application started to interest the project team. The project team knew that the MVN Awinda could be applied with Unreal Engine 4, but how to do it?. Unreal Engine 4 is a game engine with tools for creation of games, rendering engine for the graphics of the game, physics engine which defines for example gravity and how objects behave when they interact with each other in the created world or game and much more (*What is Unreal Engine 4*).

The MVN Awinda have support for linking the system with this game engine in order to replicate the movement to the character in game done by the person using the system. Another important tool when creating this new world is a VR-headset, examples of these headsets could be the HTC Vive or the Oculus rift. The VR headset creates a link between the in game characters head and eyes and allows the user to gain first person view in game and experience the world or game as close as the real world.

By combining the unreal engine 4, the MVN Awinda and a VR headset creation of a world, room or game where the movement and vision of the user is replicated is now possible. With this new world basically scenario can be created and experienced as it was the real world. Evaluation of a new factory where the engineers could evaluate placement of machinery, width of isles and much more is now possible as long as the plant is designed with CAE tools.

7.1.2 Further development of the MVN Awinda

There are also some improvements from Xsens that can make the system better. Xsens are currently developing sensors that use GPS-data instead of the magnetometers to determine true north (*Xsens Research*). This eliminates the problem with the magnetic disturbances in the car, and gives the possibility to conduct measurements while the test subject are actually driving the car. This feature have hardware support in the MVN Link but still lacks support from their software. The slowest stage of the method capture drivers posture was the application of the sensors to the test subject. If some faster way to apply the sensors were developed, that would cut down the measuring time considerably.

7.2 Recommendations

There are some problems with the MVN Awinda today that may very soon be solved by Xsens. The current generation of the MVN Link have hardware support for the use of GPS-data, which the Awinda does not have *(telephone interview with employee at Xsens)*. The only thing the Link needs to work better during drive is a software update. This can be an argument for acquiring a MVN Link instead of an Awinda. On the other hand the Link is more bothersome to fasten on the test subject even if just straps are used instead of the Lycra suit, making the slowest part of the method even slower. Because Xsens have not yet released the software update for the incorporation of GPS-data instead of the magnetometers. There is no way to measure how reliable this system would be, so buying the system and then waiting for the update would be a bit of a gamble. The use of the Link with the Lycra suit could be a good way to decrease the measurements error, due to the movement of the sensor. The Lycra suit makes the sensors stay more securely in place than the Velcro straps do, but the use of the Lycra suit constrain which test subjects can be used, due to body shape.

7.3 Final Result

The final result from the concept scoring, the developed method and the questionnaire will be presented in this section.

7.3.1 The concept scoring

To be able to select a concept as a data gathering tool the concept scoring matrix by (Ulrich and Eppinger 2012) was utilized. The scoring was done in three steps, first against the most important needs then the second and last the third. The choice of doing this in three steps was to increase the resolution of the scoring in order to choose the right concept for this task. The final score for each concept and scoring will be presented in figure 7.1.

Concept	Must	Should	Would
MVN Awinda	3.61	3.5	3.44
Qualisys Miqus	3.34	3	2.96
Faro Freestyle	3.15	X	X

Figure 7.1: Summary of the concept scoring

7.3.2 The method capture drivers posture

The developed method capture drivers posture consists of four different stages, the drive stage, applying the system, data collection and answering the questionnaire. Initially the thought was to capture the drivers posture during drive of the vehicle, due to technical limitations in the data gathering tool it would not be possible to collect data during drive. The design of the method makes it possible to imitate a driving scenario in order to capture the drivers posture. In the first stage the test subject drives the vehicle on a predefined route and adjusts the seat into a comfortable position. When the vehicle is parked the system is applied to the driver and followed by the next stage data collection. During this stage the driver sits in the vehicle and her/his posture is captured. Lastly the system is removed and the test subjects answers a questionnaire. The method capture drivers posture can be incorporated in current seat position clinic at the ergonomics department. The use of this method adds 15 minutes (10min for equipping the system to the test subject, and 5min measurements) to current clinic and this fulfills the need that was set to not add more than 15min to current the clinic.

7.3.3 The questionnaire

A questionnaire was utilized at the end of the method in order to verify that the driver had assumed a comfortable driving position but also to evaluate the method. The questionnaire consists of 11 questions with a ranking scale which goes from 1 to 10, a total of n=45 test subjects participated. The complete questionnaire can be seen in appendix I.1 and the average result from each question is presented in figure 7.2.

Question	Average score
1	9.3
2	7.8
3	8.4
4	7.2
5	7.8
6	9.5
7	8.6
8	9.4
9	8.9
10	9.4

Figure 7.2: Average score from the questionnaire

7.4 Final discussion

In this section discussion about the outcome, execution and evaluation from the project method development of capture drivers posture will be held.

7.4.1 Time management

At the beginning of the project a preliminary time plan was constructed. The whole project time was planned at a weekly basis and activities were connected to each week, the initial time plan can be found in appendix C.1. Working in a project demands that the assigned project team can be flexible and adapt to rapid shifts that occur during the course, in the project capture drivers posture the team has encountered many shifts and been forced to change and adapt to them. In appendix B.1 the new and revised time plan can be found.

The first deviation from the original time plan occurred during the first week of the project, the two planned activities PEST and mission statement were replaced by a SWOT-analysis and stakeholder identification. This was done since the project team evaluated that a SWOT-analysis will provide a good enough point of departure for the project and the next weeks activity was collect needs and without knowing the stakeholders collecting needs would become much more difficult and less accurate. Another discarded activity was the creation of a prototype, when the project had come to this stage the project team evaluated that there was no need for a prototype. The major change done in the the plan is the swap of two stages in the *data collection and verification* phase. The two stages that shifted place were *verification of data and method* and *Testing and data collection.* At first testing and data collection was to be done before the verification of data and method, due to the problem explained in 4 development and verification of the data collecting concept had to be done before. Another major change is that the project team had to schedule one more week then planned. The decision to extend the project for one more week was done since the analyse of the gathered data and report writing took longer then initially expected.

7.4.2 The product development process

The main method applied in this thesis is a modification of the generic product development process explained in 1.3.1. Why the product development process was chosen for a method development project has mainly two reasons. The first reason is because both team members are familiar with the method and have worked with it several times before. The second aim presented in 1.2.1, is to identify and develop a suitable tool and method for data gathering. As mentioned by Ulrich and Eppinger (2012) the product development process contains of six different phases with activities linked to each phase and provides a good work structure to accomplice this type of projects, also the flexibility of the process is preferred since no project is like the other even if they gives the impression of it.

7.4.3 Fulfillment of aim and objective

The aims established for the project method development of capture drivers posture can be found in section 1.2.1. The first aim have two major sections, identification of a suitable tool for data gathering and development of a method to capture the data. The first three objectives listed in 1.2.2 are connected to the first aim, identify a data gathering tool and develop a method. In order to evaluate how well the project aims are reached, is to look at the objectives set for the project. To identify the critical parameters which has an impact on the drivers posture a workshop was conducted with an experienced team in the field of ergonomics, complete description and result can be found in appendix A.2.8. The second objective was approached in two sections of the report 2 and 3 were several suitable concepts were developed and evaluated. First a range of possible technologies were tested and evaluated in order to see if they could go to the next stage of the process which is the selection stage. In the selection stage all potential candidates were evaluated against each other and a set of criteria which were collected during interviews with the taskmasters and stakeholders in the project. The third objective was obtained with help from the results and knowledge gained from 4 and a method was developed with respect to these perquisites and limitations. The last objective is the only one which is connected to the last aim, perform clinics to gather data for improvement of the DHM. When the final method was developed 5 then it was applied and clinics performed with n=45 subjects in order to collect the necessary data for improvement of the DHM. As an final conclusion is that all the set objectives for the project method development to capture drivers posture are fulfilled. As for the aim the first one is clearly reached with help of the objectives. The second aim regarding improvement of the DHM is partly complete as for the objective which is clearly reached and all the necessary data is collected. The last thing that is needed in order to complete the last aim is to insert the collected data into Volvo cars DHM software and compare the result. Due to limitations in time the final task was down prioritized and only the required data were provided.

7.4.4 Needs assessment

In appendix D.1 the complete needs list with requirements that the final data collecting tool has to meet. One of the most important needs was that the concept could be applied during drive, as the project continued flaws in the robustness of the final concept was revealed. The final concept could not be applied during drive because of interference from the magnetic fields generated by the vehicle. The discovery of that one of the most important needs could no be meet by the selected concept was a backlash but measures were made to minimize the problem as good as possible. As discussed in chapter 3 that even if the MVN Awinda concept received a 1 as score i wouldn't change the outcome of the scoring. If the decision to proceed with another concept instead of the MVN Awinda the project team thinks that it would become much more difficult to incorporate the developed method into the existing seat position clinic at Volvo car and as a result non of the projects aims would been accomplished.

7.4.5 Evaluation of the rating in the concept scoring

As knowledge increased about the chosen concept and how it performed in the data collection clinics an evaluation of how the rating were set for each need will be discussed here. The discussions will be divided after the different needs categories must, should and would needs. Discussion will only be about the rating for the MVN Awinda system since it was the final concept and only the needs that is subject for a change in the rating will be discussed.

7.4.5.1 The must needs

When reevaluating the scoring chart it is some needs that the systems couldn't fulfill and have received a score for it as it could. The needs the system was unable to fulfill is *Can detect the distance from back of head to head rest*, *Can detect the location of the top of the head*, *Can detect eye position*, *The concept can be applied during drive* and lastly *Data collection can be done without interruptions in the test session.* Since the system couldn't fulfill any of these needs and should have received a score of 1 the final choice of concept might look different.

7.4.5.2 The should needs

As for the should needs the system was capable to fulfill all except one of them, *output data is compatible with virtual models*. As for this need the projet teams thought was that the generated output data should be able to be imported into Volvo cars own virtual models without any extra work, this was not the case. MVN Awindas output data is compatible with a variety of different software but not with anyone that is in use at Volvo cars. Maybe that this criteria should have recivied a lower rating than it did but it wouldn't change the outcome of scoring two.

7.4.5.3 The would needs

In the section with the woulds needs the final concept cloud fulfilled all except for two of the who would have received a different score. The two needs that the system couldn't meet were *contact area between thighs and the seat* and *The concept can provide longtime data gathering.* Both criteria has received a score of 1 exactly as they should, other then the two needs mentioned no other were of interest regarding a new rating.

7.4.5.4 Summary

Out of 34 different needs the final concept was unable to fulfill 8 out of these, on these needs it would have received a rating of 1. The only section that could have been affected by this is the "must needs", these are the most important needs for the whole project. But as knowledge has increased about the task and the problems that can occur the project team thinks that no other concept would have solved the task better then the chosen one.

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A

The prestudy

This is a summary from the prestudy done in the project method development of capture drivers posture

A.1 Theory

A.1.1 Identification of stakeholders

The reason to identify and capture stakeholders is to provide a path for the organization to follow in order to maximize it's value to actors involved in the organization (Cameron et al. 2008). The main goal with the identification of stakeholders is to map and pinpoint important relationships affecting organization's effectiveness. The identification is done so the organization knows where to focus in order to maximize it's value output.

To identify these stakeholders three main criterias can be assessed. Firstly stakeholders must hold assets that are critical to the enterprises success. Secondly stakeholders must put their assets at risk in the enterprise and lastly stakeholders must have sufficient power to compel influence (Cameron et al. 2008).

A.1.2 Power-Interest grid

When working with a lot of different stakeholders difficulties can occur when prioritising, who is our most important stakeholder (Ackermann and Eden 2011). As a solution to the problem the power-interest grid has been developed. The grid consists of two axis which have power on the z-axis and interest on the y-axis. The two terms power and interest corresponds to how much power each stakeholder has over the project and of course how great their interests are in it.
To classify the importance of each stakeholder the power-interest grid are divided into four different categories, one for each quadrant. In the first quadrant stakeholders are labeled as *players*. Players are stakeholders with high power and interest, these stakeholders are the most important for the project. Stakeholders in the second quadrant are considered as *subjects*. The subjects have high interest in the project but low power and are not able affect the course of the project. Subjects can be good to form alliances with or convert into players. In the third quadrant the stakeholders are categorized as *crowd*. Stakeholders in the crowd have low power and low interest. This group of actors doesn't need to be considered as important

forces in the project. Lastly, the stakeholders placed in quadrant four, the *context setters*. These are high power but low interest stakeholders, usually sharing the organizations values but unaware of it. A possibility is to raise their awareness and convert them to players. (Ackermann and Eden 2011).

A.1.3 The input-output model

Establishing the needs for each stakeholder can be done with the input-output model picture A.1. The model consist of a input arrow, a box and a output arrow. The input arrow indicates what value the project gives the stakeholder. The output corresponds to what the stakeholder will contribute to the project. (Cameron, Seher, and Crawley 2011).

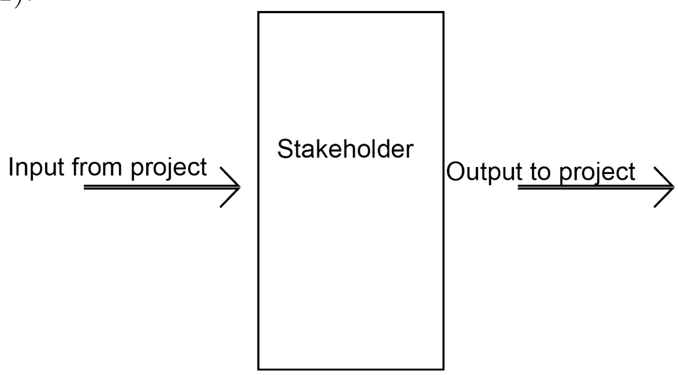

Figure A.1: The Input-Output model

A.1.4 Guidelines for interpretation of customer needs

It can be problematic to identify customer needs from collected raw data without any consistency or guide to follow. Depending on the team member who makes the interpretation, the same statement can be translated to several different needs (Ulrich and Eppinger 2012). In order to structure and provide a line of argument through out the needs identification phase Ulrich and Eppinger (2012, p. 82-83) has laid down some guidelines on how to formulate customers needs from raw data.

A.1.5 Interviews

Two types of interviews have been conducted to gather data for the prestudy, *unstructured interview* and *semi-structured interview*. During a unstructured interview open questions are asked and the interviewee can talk about what they think is important. The interviewer has the possibility to ask follow up questions on interesting answers that the interviewee gives. A unstructured interview is good to start with when the interviewer tries to establish a base of knowledge, since an unstructured interview provides a lot of qualitative information about a subject. A semi-structured interview follows a structure of which subjects should be addressed during the interview and these have been planned before. As a compliment during the interview the interviewer can use a mediating tool to get visual data from the interviewee. Since the interview lacks a strict structure the interviewer can steer the interview, but also go with what the interviewee are saying and ask follow-up questions. (Abrahamsson et al. 2010)

A.1.6 Categorising needs

It can be difficult to work with a large number of needs. To get a more manageable list of needs to use in the development process, the needs can be sorted in a *hierarchical list*. The list can be categorised in *primary- secondary-* and if there are a need for it, *tertiary needs*. The process for sorting the needs can be done in two ways. The first way of doing this is trusting to the project teams intuitive skills and let them reach a consensus when categorising the needs. The second way of approaching this task is to follow a six step guide suggested in the book Ulrich and Eppinger (2012). (Ulrich and Eppinger 2012)

A.1.7 Affinity diagram

A affinity diagram can be used to sort large amounts of verbal data. According to Bergman and Klefsjö (2010) the procedure to make a affinity diagram are, to first define what the topic of the collected data are . This is written on a large piece of paper. All team members write down what they regard as important issues on small notes. All the notes are gone through, and identical notes are removed. The team members gets to group the notes as they see fit, when all notes are grouped a heading are written for each group. Then arrows are drawn between groups that influence each other. When the team are happy with the arrows and placement of groups, the diagram are made permanent, by gluing the notes in place. Each team member gets to rank the groups, and the ranking are added to see which three groups that are the most important. Lastly the team members sign the paper to show that they agree with the diagram. (Bergman and Klefsjö 2010)

A.1.8 Workshop

To evaluate chosen opportunities or evaluate methods, a in-person workshop can be used. In the format presented by Ulrich and Eppinger (2012), the workshop start with a presentation of the subject and the alternatives that will be treated during the workshop. After the presentation each participant are asked to *multivote*, this is done by giving the participants "dots" that can be placed on printed notes with the different suggestions, to indicate which ones they think are the most important.

A.2 Method

A.2.1 Stakeholder identification

Identification of the stakeholders for the project drivers seat posture were done in the same manner as Cameron et al. (2008) proposes, by asking the question "who are the stakeholders of the method to measure joint angles and spine curvature, and the collected data to whom benefit might flow". The next step with this question in mind were to brainstorm potential stakeholders, each stakeholder were noted on a post-it, a total of 20 stakeholders were identified. After the identification step the stakeholders were clustered into subgroups. Each subgroup contained between 3-5 stakeholders, and a total of 5 subgroups. The clustering were done to ease the last step, stakeholder prerequisites classification.

After a discussion with the supervisors for the project, a decision was made to break down the stakeholder *internal departments at VCC* to three new ones. The new stakeholders became three departments who all have interest in the project, *seating comfort, passive safety* and *The ergonomics department*. Another stakeholder were also identified, the software manikin RAMSIS.

A.2.2 Stakeholder classification

To determine the importance of each stakeholder the power-interest grid (Ackermann and Eden 2011) were applied. The previous identified stakeholders were placed on a big sheet of paper representing the grid. The grid helped the project team to determine how much influence each individual stakeholder have over the project. Picture 1.2 shows the distribution of the stakeholders in the grid, the size of each circle indicates the power of the stakeholder. One conclusion of the stakeholder distribution on the power-interest grid is that stakeholders ranked as players will have their needs prioritized higher than stakeholders in the other quadrants.

A.2.3 Stakeholder prerequisites identification

As identification approach for the stakeholder prerequisites, the input-output model suggested by Cameron, Seher, and Crawley (2011) was used. Each subgroup was specified on a post-it and placed on a white sheet of paper. Then a brainstorming session took place and input/output for each group was specified. The prerequisites identified for each stakeholder derives from the input and output.

As for identification for the stakeholders prerequisites each input were written down on a post-it note, one note for each input. On the backside of each note a number ranging from 1 to 23 were also written down. The numbers correspond to the stakeholders in table starting with VCC as number one and so on. This were done to hide which stakeholder belonged to which input. The purpose with hiding the stakeholders were to get as neutral identification process as possible, without any stakeholder influencing the team members identifying the prerequisites. Since needs identification may be influenced by the team member who discovers it (Ulrich and Eppinger 2012). Then the post-it's were put on a big piece of paper.

From the collection of post-it's one were drawn at random and the project team then identified possible prerequisites for that input. The prerequisite identification followed the guidelines formulate by Ulrich and Eppinger (2012).

A.2.4 Stakeholder statements

The stakeholder-prerequisites that was identified in A.2 worked as a guideline when establishing the stakeholder statements. The statements were written on a post it and the grouped on a *hierarchical list*. Similar statements were grouped together, placed on each other and transformed into a single card. The subgroups were then labeled describing the general stakeholder for that subgroup. When all groups were labeled and organised each individual statement was reevaluated based on were the statements stakeholder appeared on the power-interest grid, 1.2. Statements belonging to stakeholders in the *crowd* quadrant were seen as not important and immediately discarded.

A.2.5 Statements from interviews

To get a deeper understanding of the possible needs from the stakeholders ranked as players, additional in depth interviews were conducted with them. The input categories helped the project group to state six new categories, *method, input data, equipment, test environment, output data* and *documentation*. The two in depth interviews were semi-constructed and the new categories were used to provide a structure to the interview. The interviews were made with the supervisors and with the department active safety at VCC. As a compliment, a mediating tool, in the form of a laminated figure was used see A.2. The interviewees were asked to mark which measurements they would like to have as output from the method. The interviews were audio recorded and later on transcribed into quotes, forming the stakeholder statements.

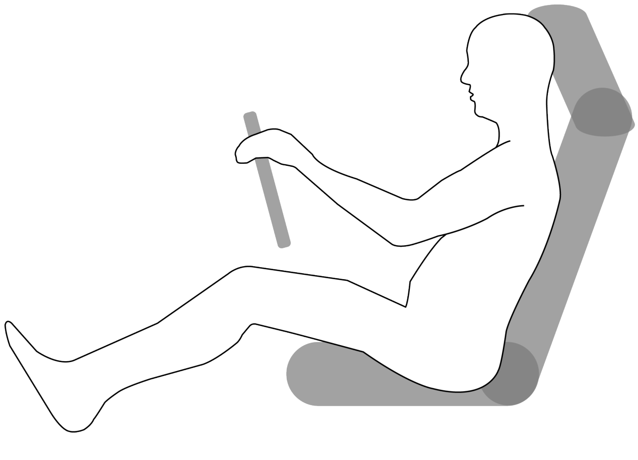

Figure A.2: The mediating tool that was used during the interviews

A.2.6 Categorising the statements

The statements from the two interviews and the statements that origin from the stakeholder prerequisites were all written down on separate notes, and reviewed again to identify any redundant statements, if redundant statements were found they were grouped as one and the most suited statement was kept and the others discarded. The project team started with a total of 51 statements, during the grouping and elimination 13 were discarded and 2 rewritten. Then the remaining statements were sorted together in a affinity diagram, (Bergman and Klefsjö 2010), when the categorising was agreed upon, each group of statements was given a label. Then the large groups were divided into subgroups, and given labels. The last step in the affinity diagram process is to create dependencies between the subgroups, a arrow was drawn from the latter to the former. To make the diagram permanent the notes were glued in place, as a final step the team members signed the paper to show their agreement on the task.

A.2.7 Creating the needs

To formulate the needs the project team sat down with the affinity diagram and discussed each statement. To each statement a need were constructed and paired with the statement and affected stakeholder. The team followed Ulrich and Eppingers guidelines (Ulrich and Eppinger 2012).

A.2.8 Relative importance of needs

To decide the relative importance of the needs, the project team first did a brainstorming session. All needs were reviewed and scored based on how important the team thought the need was. As a point of departure when deciding the needs importance the team relied information about the project collected in previous interviews and activities. Due to the teams inexperience in needs formulation and rating, it was decided to conduct a workshop together with the ergonomics department at VCC. The purpose with the workshop was to verify the needs and the rating done by the project team. An invitation was sent out to seventeen employees at 91320, out of these seventeen, eight people attended the workshop.

In the beginning a brief presentation about the project scope and our findings. This was done to create a understanding about the project among the participants, instructions about the workshop were also included.

To provide the participants with the needs, the project team had created laminated "needs cards". Each card containing the needs from each category established with the affinity diagram. This were done to give the participants a holistic view of the needs and opened up the opportunity for discussion among the participants. The first step of the workshop were to divide the big group in to three smaller groups and provide them with a needs card and a multimarker pen, one colour for each group. Then each group discussed the needs and the card, if some needs were unclear the group had the possibility to make a comment on the card. After discussion were done each member got three coloured dots to rank the three most important needs on each card. The green dot was used to indicate the most important, the yellow the second most important, and the blue as the third most important. After the individual ranking each member signed the bottom of the card and took a new one. This were repeated until all the categories had been rated by all the participants.

The total time this exercise took were one hour and fifteen minutes. Ten minutes to prepare and set up the computer. One hour to perform the workshop and five minutes to close the workshop.

As a final step the needs were categorised in to three different groups *Must*, *Should* and *Would*. This was done accordingly to suggested method by (Ulrich and Eppinger 2012). The project team did utilize one of the key stakeholders, the supervisors for input to the discussion but also the rating on the needs cards acquired from workshop one.

B
Time plan for the project method development of capture drivers posture

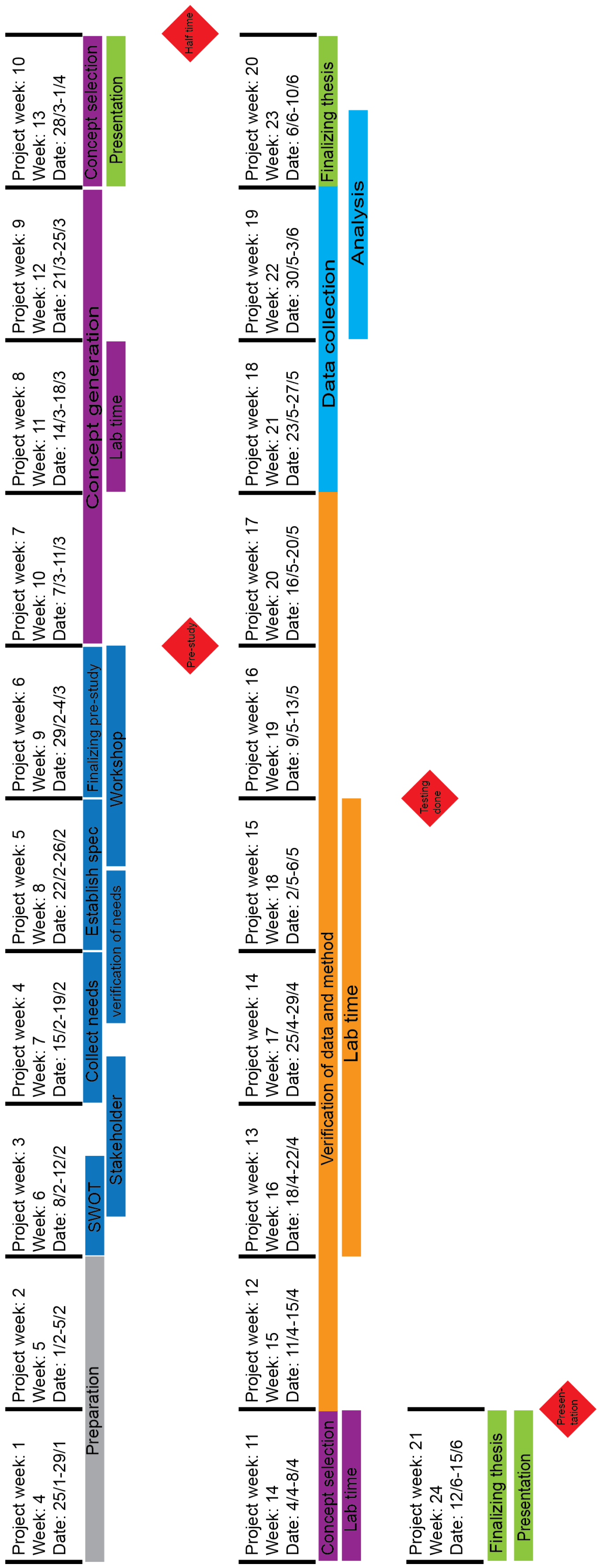

Figure B.1: Gantt chart for the project method development of capture drivers posture

C

Initial time plan for the project method development of capture drivers posture

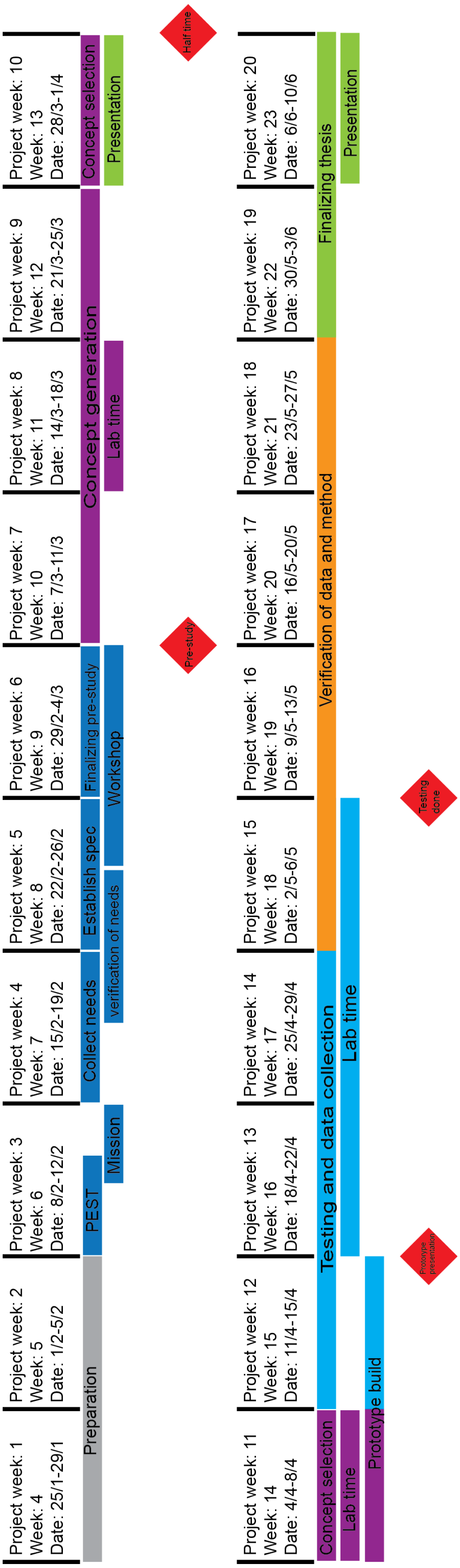

Figure C.1: Initial gantt chart for the project method development of capture drivers posture

D
Complete customers needs list

Musts(5)	Need	Metrics	
	Applicable to different body types	The method suits 5- to 95-percentile	
	Applicable to different vehicle models.	Universal fastners	
	Gives the test subjects the freedom to be positioned as desired.	Does not limit the seat adjustment range	
	Applicable with existing input data available at VCC	All input data is recived from VCC	
	Can detect the location of the buttocks	Position/angle/other	
	Can detect the location of the hip joint	Position/angle/other	
	Can detect the ankle point	Position/angle/other	
	Can detect the location of the knee	Position/angle/other	
	Can detect the location of the wrist	Position/angle/other	
	Can detect the location of the elbow	Position/angle/other	
	Can detect the shoulder point	Position/angle/other	
	Can detect the angle between the fastening of the collar bone to the shoulder	Position/angle/other	
	Can detect the distance from back of head to head rest	Position/angle/other	
	Can detect the location of the top of the head	Position/angle/other	
	Can detect eye position	Position/angle/other	
	Can be used outside of the VCC area	Mobile method	Removed due to top score for all
	Can detect the curvature of the spine	Position/angle/other	
	The conceptcan be applied during drive	Equipment doesn't affect the vehicles driving performance	
	Can sort out extreme postures, (reaching for the glove box etc.)	Position/angle/other	
	Data collection step can be repeated, with the same input and get the same output	Same result can be achived in different sessions	
	Accuracy in measurements, the measurements are very accurate	Maximum deviation from true value (5mm, 1°?)	
	No interfeence on the test subjects driving skills during tests	Doesn't limit the seats adjustment range, Equipment doesn't affect the vehicles driving performance, Drivers field of vision are not ob	
	The concept shows differences in posture related to vehicle model	Comparable result between tests	
	Data collection can be done with out interuptions in the test session	New need, due to new information (the system cant loose its calibration)	
Should(4-3)			
	The test leader finds it easy to set up the testing equipment	Time to set up test equipment are less or equal to 10minutes, The method doesn't add more time to the tests the specified	
	The method conforms to testing time guidelines	The method doesn't add more time to the tests the specified	
	The method serves as a compliment to existing tests	The method can be applied simultaneously as other test	
	Captured data is directly compatible with virtual models	Maximum deviation between test environment and CAD-model is 5mm	Removed due similar need
	Easy to analyze output data	Time for analysing the result doesn't exceed the total test time	
	The concept can collect several different parameters	The method can collect more then one parameter	
	Output data is compatible with virtual models	The output data can be used in models att VCC	
	The method can be applied in customer's and competitors cars	Universal fasteners, Storage capacity for collected data, Equipment doesn't affect the veh	Removed due similar must need
Would (3-2)			
	Can collect quantitative data	The method captures data more then once during a test	
	The method is compatible to any driving scenario	Same result can be achived in different sessions	
	The method is easy to learn	Test leader can perform tests after one trial and reading the instructions	
	Easy to interpret the continous data	Time for analysing the result doesn't exceed the total test time	
	Output data follows VCC standards	The output data can be used in models att VCC	
	The methods detects abnormal seating postures	Detectes extreme points	
	The method collects only relevant data	Captured parameters are verified by supervisors	Removed due to redundancy
	Contact area between thighs and the seat	Position/angle/other	
	The method can provide long term data gathering	Storage capacity for collected data	
	The method can be applied when the vehicle is stationary	Method can be applied when the car dosen't move	
	The concept can measure the whole body	One measurement session for the whole body, The method suits 5 to 95 %tile	
	The concept can collect high frequency data	The method can collect data more then 15 samples/s	
	The test leader can specify a range for the data collection	Sample time can be specified	

Figure D.1: Complete customers needs list

E

Concept screening

	Concepts					
	A	B	C	D	E	F
Selection criteria	**Faro Freestyle**	**MVN Awinda**	**Kinect**	**Kinect x2**	**Miqus**	**Goniometer**
Sutible on different body types	+	0	0	0	+	0
Applicability in different vehicles	0	0	-	-	-	0
No affect on the test subjects driving capabilites	+	+	+	+	+	0
Accuracy in measurements	+	+	0	0	+	0
Cost	-	-	-	-	-	0
Session time	+	+	+	+	+	0
Set-up time	0	-	-	-	-	0
Ease of use	-	-	-	-	-	0
Ease of output data analysis	-	-	-	-	-	0
Sum +'s	4	3	2	2	4	0
Sum 0's	2	2	2	2	0	9
Sum -'s	3	4	4	4	5	0
Net score	1	-1	-2	-2	-1	0
Rank	1	3	4	4	3	2
Continue?	Y	Y	N	N	Y	Y

Figure E.1: Concept Screening

F
Concept Scoring

Selection criteria	Weight	Concept							
		A Goniometer(ref)		C MVN Awinda		D Qualisys Miqus		E Faro Freestyle	
		Rating	Weighted score	Rating	Weighted score	Rating	Weighted score	Rating	Weighted score
Applicable to different body types	12%	3	0,36	3	0,36	4	0,48	4	0,48
Applicable to different vehicle models.	5%	3	0,15	4	0,2	1	0,05	5	0,25
Gives the test subjects the freedom to be positioned as desired.	6%	3	0,18	4	0,24	5	0,3	4	0,24
Applicable with existing input data available at VCC	5%	2	0,1	4	0,2	3	0,15	3	0,15
Can detect the distance from back of head to head rest	3%	2	0,06	1	0,03	5	0,15	4	0,12
Can detect the location of the top of the head	1%	1	0,01	3	0,03	5	0,05	4	0,04
Give joint angles/segment position	14%	3	0,42	4,5	0,63	4	0,56	2	0,28
Can detect eye position	2%	1	0,02	2	0,04	4	0,08	3	0,06
Can detect the curvature of the spine	10%	1	0,1	3	0,3	2	0,2	1	0,1
The concept can be applied during drive	9%	2	0,18	4	0,36	1	0,09	3	0,27
Can sort out extreme postures, (reaching for the glove box etc.)	2%	1	0,02	3	0,06	3	0,06	1	0,02
Data collection step can be repeated, with the same input and get the same output	10%	3	0,3	4	0,4	3	0,3	4	0,4
Accuracy in measurements, the measurements are very accurate	5%	3	0,15	3	0,15	4	0,2	4	0,2
No interfeence on the test subjects driving skills during tests	4%	2	0,08	4	0,16	4	0,16	3	0,12
The concept shows differences in posture related to vehicle model	9%	3	0,27	4	0,36	4	0,36	3	0,27
Data collection can be done without interuptions in the test session	3%	3	0,09	3	0,09	5	0,15	5	0,15
	100%								
	Total score	2,49		3,61		3,34		3,15	
	Rank	4		1		2		3	
	Continue?	N(Used as ref through the scoring)		Y		Y		N	

Figure F.1: Scoring against the must needs

		Concepts					
		A		B		C	
		Goniometer(ref)		Qualisys Miqus		MVN Awinda	
Selection criteria	**Weight**	**Rating**	**Weighted score**	**Rating**	**Weighted score**	**Rating**	**Weighted score**
The test leader finds it easy to set up the testing equipment	20%	3	0,6	2	0,4	3	0,6
The method conforms to testing time guidelines	20%	2	0,4	4	0,8	4	0,8
The method serves as a compliment to existing tests	15%	3	0,45	3	0,45	3	0,45
Easy to analyze output data	20%	3	0,6	2	0,4	4	0,8
The concept can collect several different parameters	10%	1	0,1	5	0,5	4	0,4
Output data is compatible with virtual models	15%	3	0,45	3	0,45	3	0,45
	100%						
	Total score	2,60		3		3,50	
	Rank	3		2		1	
	Continue?	(Used as ref through the scorin		Y		Y	

Figure F.2: Scoring against the should needs

		Concepts					
		A Goniometer(ref)		B Qualisys Miqus		C MVN Awinda	
Selection criteria	Weight	Rating	Weighted score	Rating	Weighted score	Rating	Weighted score
Can collect quantitative data	12%	2	0,24	4	0,48	4	0,48
The method is compatible to any driving scenario	12%	3	0,36	1	0,12	4	0,48
The method is easy to learn	10%	3	0,3	2	0,2	3	0,3
Easy to interpret the continous data	7%	2	0,14	2	0,14	5	0,35
Output data follows VCC standards	3%	3	0,09	3	0,09	3	0,09
The methods detects abnormal seating postures	7%	2	0,14	4	0,28	4	0,28
Contact area between thighs and the seat	2%	1	0,02	3	0,06	1	0,02
The concept can provide long term data gathering	8%	1	0,08	3	0,24	1	0,08
The method can be applied when the vehicle is stationary	10%	3	0,3	3	0,3	3	0,3
The concept can measure the whole body	10%	1	0,1	2	0,2	4	0,4
The concept can collect high frequency data	9%	1	0,09	5	0,45	4	0,36
The test leader can specify a range for the data collection	10%	3	0,3	4	0,4	3	0,3
	100%						
	Total score	2,16		2,96		3,44	
	Rank	1		2		1	
	Continue?	N		N		Y	

Figure F.3: Scoring against the would needs

G

Result from the MVN Awinda experiment

Run	Sensor warm up (A), Stand	Calibrate outside the car (B)	Number of turns (C)	A*B	A*C	B*C	A*B*C	Y [s]
1	+	+	+	+	+	+	+	87
2	-	+	+	-	-	+	-	59
3	+	-	+	-	+	-	-	38
4	-	-	+	+	-	-	+	43
5	+	+	-	+	-	-	-	126
6	-	+	-	-	+	-	+	85
7	+	-	-	-	-	+	+	89
8	-	-	-	+	+	+	-	27
Estimated	31.5	40	-25	3	-20	-7.5	13.5	

Figure G.1: Result from the MVN Awinda experiment in a V40

Run	Sensor warm up (A),	Calibrate outside the car (B)	Number of turns (C)	A*B	A*C	B*C	A*B*C	Y [s]
1	+	+	+	+	+	+	+	113
2	-	+	+	-	-	+	-	23
3	+	-	+	-	+	-	-	153
4	-	-	+	+	-	-	+	35
5	+	+	-	+	-	-	-	109
6	-	+	-	-	+	-	+	40
7	+	-	-	-	-	+	+	43
8	-	-	-	+	+	+	-	37
Estimated	70.75	4.25	23.75	8.75	33.25	-14.375	-22.75	69.125

Figure G.2: Result from the MVN Awinda experiment in a V60

Run	Sensor warm up (A), Stand	Calibrate outside the car (B)	Number of turns (C)	A*B	A*C	B*C	A*B*C	Y [s]
1	+	+	+	+	+	+	+	66
2	-	+	+	-	-	+	-	29
3	+	-	+	-	+	-	-	75
4	-	-	+	+	-	-	+	31
5	+	+	-	+	-	-	-	167
6	-	+	-	-	+	-	+	33
7	+	-	-	-	-	+	+	81
8	-	-	-	+	+	+	-	26
Estimated	67.5	20.5	-26.5	18	-27	-26	-21.5	

Figure G.3: Result from the MVN Awinda experiment in a XC90

H

Verification

H.1 Subjective verification

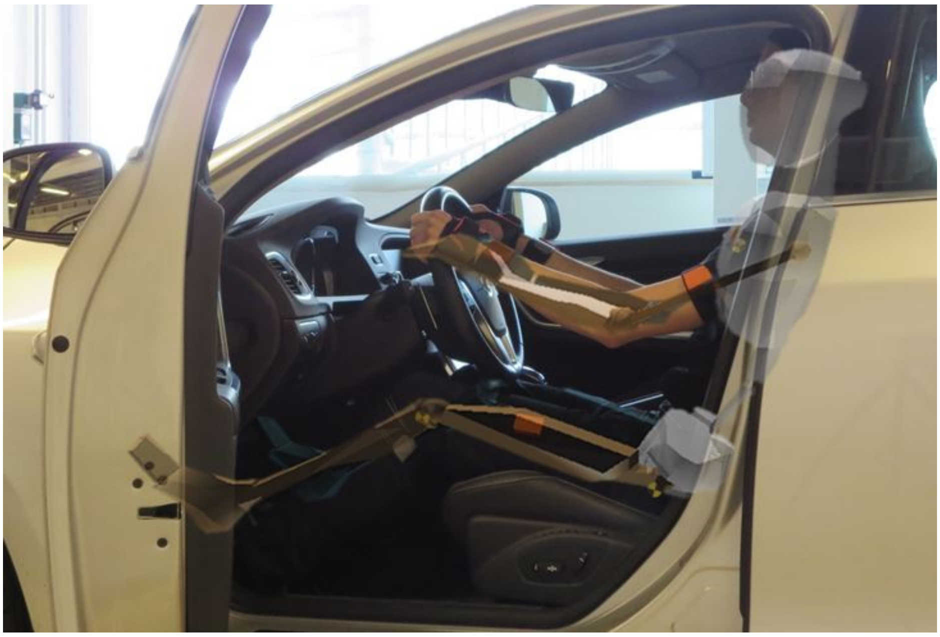

Figure H.1: Test subject positioned in car, with the MVN model layed over for comparison

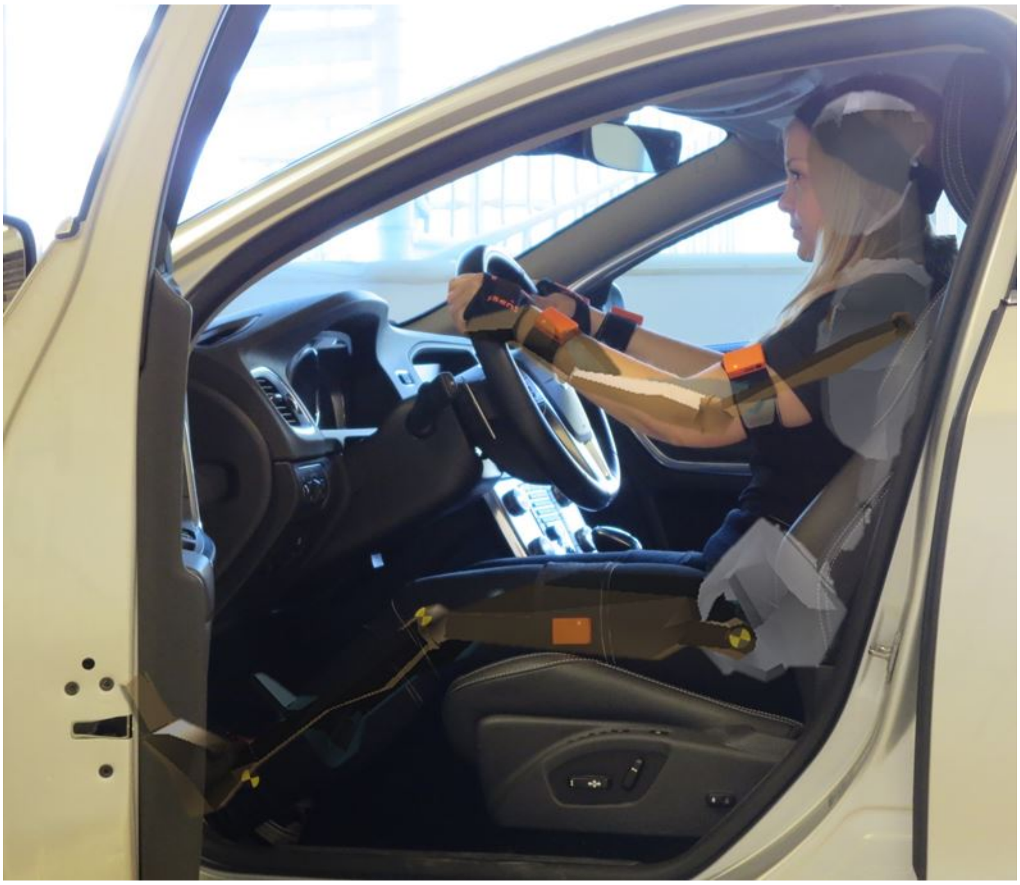

Figure H.2: Test subject positioned in car, with the MVN model layed over for comparison

Figure H.3: Test subject positioned in car, with the MVN model layed over for comparison

Figure H.4: Test subject positioned in car, with the MVN model layed over for comparison

H.2 ImageJ verification

		Picture	Model	Error
Verification subject1 (184,3cm)	**T-pose**			
	L-Shoulder	84,92	78,69	6,23
	R-Shoulder	83,29	77,51	5,78
	L-elbow	177,63	174,74	2,89
	R-elbow	175,65	170,49	5,16
	L-knee	171,18	171,95	0,77
	R-knee	173,4	175,08	1,68
	Spine	179,15	179,11	0,04
	Sitting			0
	Hip	97,5	104,3	6,8
	Knee	86,04	91,58	5,54
	Elbow	147,3	149,9	2,6
	Spine	140,26	144,3	4,04
	Upper-spine	155,85	156,05	0,2
	Lower-spine	162,95	163,49	0,54
	Ankle	103,49	98,89	4,6
Verification subject2(174cm)	**T-pose**			0
	L-Shoulder	91,8	84,3	7,5
	R-Shoulder	91,6	89,7	1,9
	L-elbow	177,8	175,6	2,2
	R-elbow	179,8	175,5	4,3
	L-knee	178,5	174,1	4,4
	R-knee	175,1	172,4	2,7
	Spine	175,8	177,6	1,8
	Sitting			0
	Hip	114,8	123,2	8,4
	Knee	90,9	102,5	11,6
	Elbow	128,1	128,1	0
	Spine	139,3	138,6	0,7
	Upper-spine	146,8	150,7	3,9
	Lower-spine	150,7	152	1,3
	Ankle	95,1	104,5	9,4
Verification subject3 (189,7cm)	**T-pose**			0
	L-Shoulder	89,2	85	4,2
	R-Shoulder	86,1	82,8	3,3
	L-elbow	178,3	171,7	6,6
	R-elbow	178	173,8	4,2
	L-knee	174,4	175,2	0,8
	R-knee	171,7	172,2	0,5
	Spine	176,1	175,4	0,7
	Sitting			0
	Hip	105,3	100,1	5,2
	Knee	87,5	97,5	10
	Elbow	105,9	114,4	8,5
	Spine	140,2	150	9,8
	Upper-spine	150,6	154,23	3,63
	Lower-spine	143,6	154,2	10,6
Verification subject4, (196cm)	**T-pose**			0
	L-Shoulder	90,6	82,3	8,3
	R-Shoulder	90,6	91,5	0,9

	L-elbow	172	172,7	0,7
	R-elbow	179,8	178,1	1,7
	L-knee	177,2	177,5	0,3
	R-knee	178,3	178,6	0,3
	Spine	179,3	177,8	1,5
	Sitting			0
	Hip	92,6	94,5	1,9
	Knee	91	92,9	1,9
	Elbow	107,5	117,3	9,8
	Spine	135,5	151,2	15,7
	Upper-spine	145,2	153	7,8
	Lower-spine	157,5	174	16,5
Verification subject5,	**T-pose**			0
	L-Shoulder	95,8	93,9	1,9
	R-Shoulder	98	97,7	0,3
	L-elbow	176,9	178,7	1,8
	R-elbow	173	179,2	6,2
	L-knee	178,3	176,8	1,5
	R-knee	177,1	176,2	0,9
	Spine	179,1	179,4	0,3
	Sitting			0
	Hip	96,8	106	9,2
	Knee	80,1	99,4	19,3
	Elbow	109,9	121,7	11,8
	Spine	138,3	147,8	9,5
	Upper-spine	145,3	153,4	8,1
	Lower-spine	159,9	159,9	0
	Mean			5,6

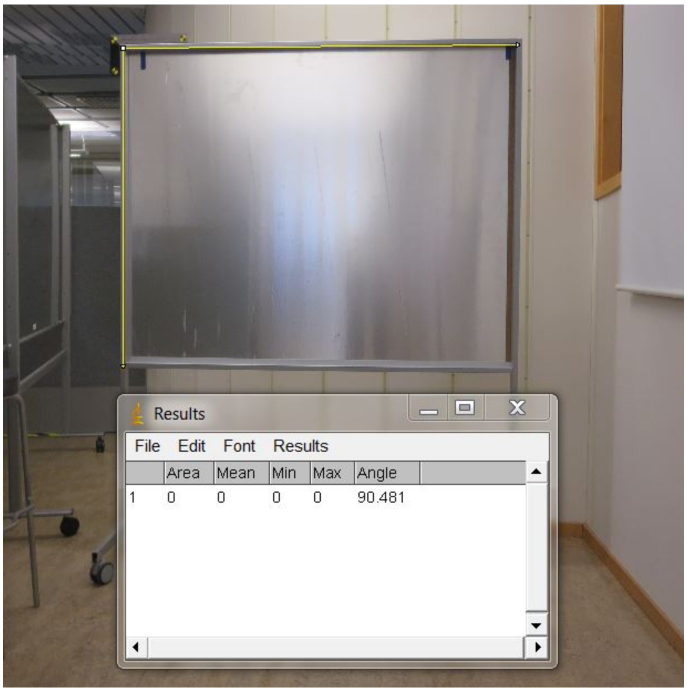

Figure H.5: Verification picture from imageJ

Figure H.6: The angle of the arm, measured in the MVN model

Figure H.7: The angle of the arm, measured in the verification picture

Figure H.8: The angle of the hip, measured in the MVN model

Figure H.9: The angle of the hip, measured in the verification picture

Figure H.10: The angle of the knee, measured in the verification picture

Figure H.11: The angle of the knee, measured in the MVN model

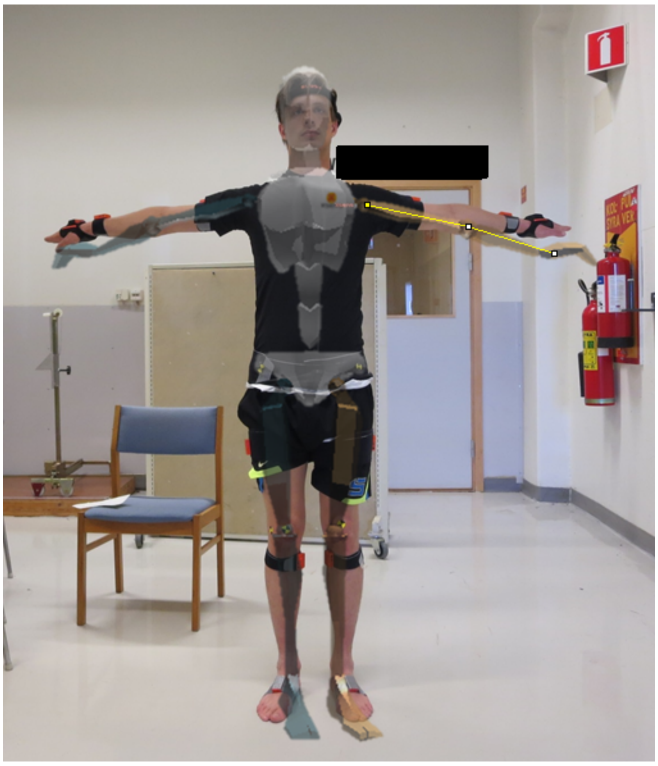

Figure H.12: The angle of the elbow, measured in the MVN model

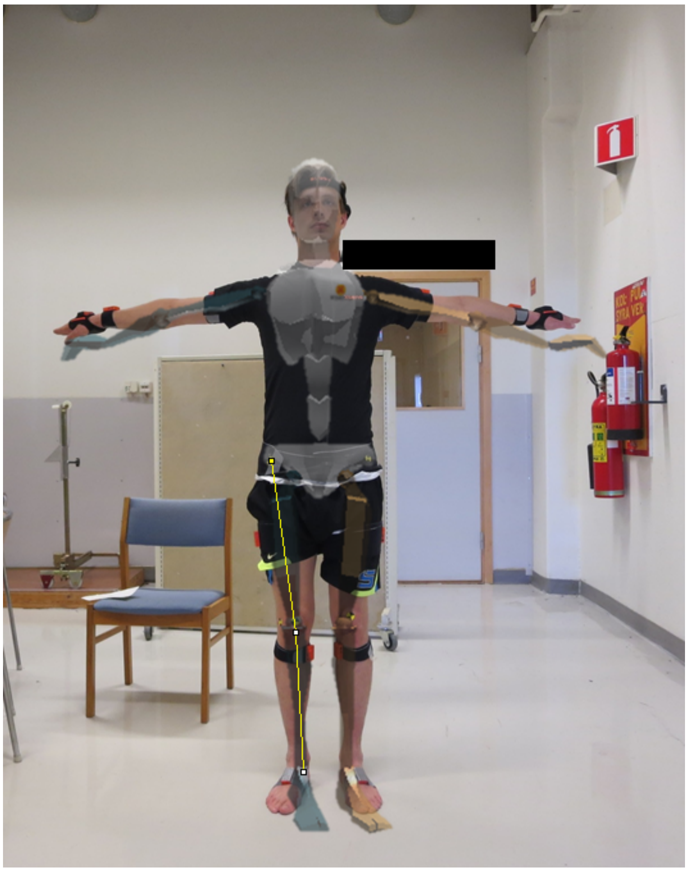

Figure H.13: The angle of the knee, measured in the MVN model

Figure H.14: The angle of the right knee, measured in the verification picture

Figure H.15: The angle of the right shoulder, measured in the MVN model

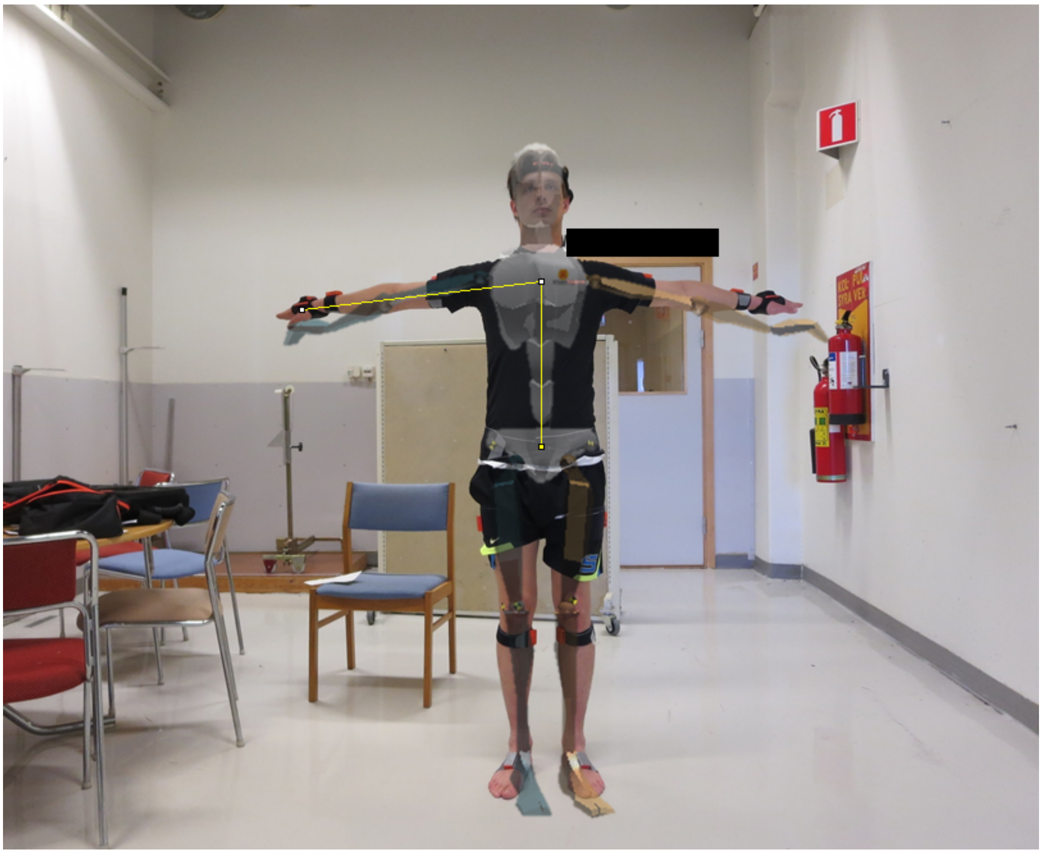

Figure H.16: The angle of the right shoulder, measured in the verification picture

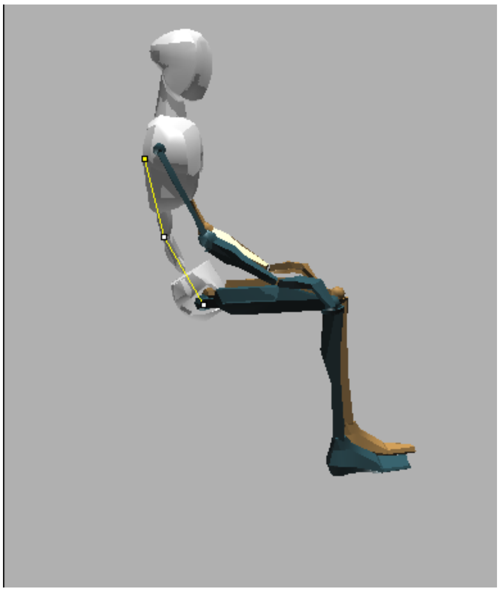

Figure H.17: The angle of the lower spine, measured in the MVN model

Figure H.18: The angle of the lower spine, measured in the verification picture

I

The questionnaire

1	2	3	4	5	6	7	8	9	10
Very bad		Bad		Ok		Good		Very good	

Questions	Rating
How would you rate your overall experience of this clinic?	
How comfortable did you experience your driving position in the V40?	
How comfortable did you experience your driving position XC60?	
Did you feel limited of the adjustment range of the seat and steering wheel in the V40?	
Did you feel limited of the adjustment range of the seat and steering wheel in the XC60?	
Did you find the test course easy to drive?	
Was the test time allocated to the test drive sufficient for you to assume your perfect driving position?	
Did the measurement equipment affect your driving position?	
Do you feel uncomfortable wearing the measurement equipment?	
Did you feel uncomfortable when the measurement equipment was applied?	
Other comments	

Figure I.1: The questionnaire used in the clinics

J

Summary of the questionnaire from drivers posture clinics

Question	TP6	TP14	TP16	TP22	TP23	TP25	TP27	TP28	TP30	TP33	TP35	TP40	TP42	TP45	Average
How would you rate your overall experience of this clinic?	8	9	9	9	10	10	9	10	10	10	9	10	10	8	9.4
How comfortable did you experience your driving position in the V40?	7	7	9	8	8	10	8	9	9	10	7	8	10	8	8.4
How comfortable did you experience your driving position XC60?	9	6	7	9	9	10	10	8	10	6	5	9	10	9	8.4
Did you feel limited of the adjustment range of the seat and steering wheel in the V40?	7	4	9	2	10	10	8	10	10	10	4	9	10	9	8.0
Did you feel limited of the adjustment range of the seat and steering wheel in the XC60?	8	3	6	2	10	10	10	10	10	4	6	9	7	9	7.4
Did you find the test course easy to drive?	10	9	9	9	10	10	9	10	10	10	8	10	10	9	9.5
Was the test time allocated to the test drive sufficient for you to assume your perfect	7	5	10	9	10	10	10	10	10	10	8	7	9	8	8.8
Did the measurement equipment affect your driving position?	10	10	10	10	10	10	10	8	10	10	5	9	10	9	9.4
Do you feel uncomfortable wearing the measurement equipment?	10	10	10	8	10	10	10	8	10	10	8	10	10	9	9.5
Did you feel uncomfortable when the measurement equipment was applied?	10	10	10	8	10	10	10	9	10	10	10	9	10	9	9.6

Figure J.1: Summary of questionnaire from short test subjects

Question	TP2	TP3	TP4	TP5	TP7	TP13	TP15	TP17	TP21	TP24	TP26	TP31	TP36	TP38	TP39	TP41	Average
How would you rate your overall experience of this clinic?	10	9	7	10	10	10	7	9	10	10	9	10	10	10	9	9	9.3
How comfortable did you experience your driving position in the V40?	8	8	9	7	8	7	6	8	6	7	10	8	8	9	9	8	7.9
How comfortable did you experience your driving position XC60?	9	8	9	8	10	8	7	7	9	9	9	10	6	10	9	9	8.6
Did you feel limited of the adjustment range of the seat and steering wheel in the V40?	5	7	10	7	8	4	5	8	6	9	10	8	6	9	5	7	7.1
Did you feel limited of the adjustment range of the seat and steering wheel in the XC60?	10	7	7	9	10	10	6	8	8	10	10	10	9	10	7	10	8.8
Did you find the test course easy to drive?	10	10	10	10	10	8	7	9	10	10	10	10	10	10	10	8	9.5
Was the test time allocated to the test drive sufficient for you to assume your perfect driving position?	10	10	8	7	8	9	4	8	6	10	9	10	10	10	10	9	8.6
Did the measurement equipment affect your driving position?	10	10	10	10	10	10	5	10	10	10	10	9	10	10	8	10	9.5
Do you feel uncomfortable wearing the measurement equipment?	10	10	10	9	10	9	5	10	10	10	10	10	10	10	10	6	9.3
Did you feel uncomfortable when the measurement equipment was applied?	10	10	10	10	10	9	8	10	10	10	10	10	10	10	10	8	9.7

Figure J.2: Summary of questionnaire from normal test subjects

Question	TP1	TP8	TP9	TP10	TP11	TP12	TP18	TP19	TP20	TP29	TP32	TP34	TP37	TP43	TP44	Average
How would you rate your overall experience of this clinic?	10	9	9	10	9	10	9	8	9	8	8	10	9	10	10	9.2
How comfortable did you experience your driving position in the V40?	9	8	6	8	8	10	5	4	5	8	7	7	9	7	6	7.1
How comfortable did you experience your driving position XC60?	10	10	9	10	8	8	8	8	6	5	8	8	10	9	8	8.3
Did you feel limited of the adjustment range of the seat and steering wheel in the V40?	10	8	5	7	7	10	7	2	4	9	5	7	9	6	3	6.6
Did you feel limited of the adjustment range of the seat and steering wheel in the XC60?	10	8	9	9	7	7	2	7	5	9	7	8	10	6	6	7.3
Did you find the test course easy to drive?	10	10	10	10	10	10	10	8	8	10	8	10	9	10	10	9.5
Was the test time allocated to the test drive sufficient for you to assume your perfect driving	8	5	10	10	10	10	8	3	9	9	8	8	9	10	10	8.5
Did the measurement equipment affect your driving position?	10	10	9	10	10	9	9	10	10	10	8	9	9	9	10	9.5
Do you feel uncomfortable wearing the measurement equipment?	10	10	8	10	8	9	8	4	10	9	6	6	9	6	6	7.9
Did you feel uncomfortable when the measurement equipment was applied?	10	10	10	10	10	8	8	8	10	9	7	8	9	10	10	9.1

Figure J.3: Summary of questionnaire from long test subjects