CHALMERS

Evaluating Comfortable Driving

Three case studies on driver's behaviour in different driving situations

Master of Science Thesis in the Master Degree Programme Industrial Design Engineering, MPDES

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Cover photo: Interior of Volvo FH model, VOLVO TRUCKS
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ABSTRACT

In the road transport field, it is a fact that truck drivers spend long hours inside the truck, sitting in the driver seat. However, sitting for long periods of time has proven to be not healthy, it leads to discomfort and fatigue, which could be possible causes of severe traffic accidents. Important research has taken place in the field of trucks, so that the truck driver population will be healthy and able to be productive also in the future.

However, the majority of the trucks are designed to support people who are close to the anthropometric means and do not take into consideration the more specific needs a driver at the boundaries of the population may have. Therefore, the really short or tall drivers are not fully supported through the design of the cockpit in an adequate amount and have to compromise their driving postures.

The CAB interior division at Volvo Group Trucks Technology is always dedicated to develop new interiors for different truck models in order to improve truck drivers' working life. More specifically, they are interested in gathering information and investigating the internal and external parameters that lead the drivers to choose a specific sitting behaviour in different driving situations. Furthermore, they are interested to know the factors that cause the transition between those different postures.

This thesis project identifies the key parameters that govern the drivers' chosen driving postures. The focus is on the internal arrangement of the driver position within the cockpit, in relation to internal and external parameters. Furthermore, there will be a focus on the extremes of people's anthropometric dimensions. The drivers' stature will be the parameter that is going to be examined, thus really tall and short people.

The project consists of three main phases which have been executed using an iterative process. The three main phases are the three case studies that were held and founded this thesis work. The first case study is the questionnaires, the second case study is the field tests in a real truck and the third case study is the driving simulator study. The results of each of the aforementioned case studies and the comparison of the outcomes gave the final conclusions and design proposals.

Keywords: Ergonomics, Human Factors, Volvo Group Trucks Technology, Comfort, Driving Postures

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1 Introduction

This chapter introduces the starting point of the master thesis project. It includes a description of the background, purpose, goal and delimitations as well as the process and the project outline.

1.1 Background

In the road transport field, truck drivers spend long hours inside the truck, sitting in the driver's seat. However, sitting for long periods of time has proven to be not healthy and can result in numerous problems, as back pain and musculoskeletal disorders. The described situation leads to discomfort and fatigue, which could be possible causes of severe traffic accidents. (Sundström, 2003)

Truck drivers' population is multitudinous, as there are almost 600,000 companies, which employ almost 3 million people. Important research has taken place in the field of trucks, so that this population will be healthy and able to be productive in the future also. Companies investigate how the truck drivers could work more comfortably and they provide many opportunities of customization inside the cab. (Commission, 2014)

As the adjustable features/opportunities increase, it is more possible that everyone could be satisfied by being able to adopt comfortable postures while driving (Gyi D. E., 2012). However, sometimes this is not enough. The majority of the trucks are designed to support people who are close to the anthropometric averages and do not take into consideration the more specific needs a driver may have. Therefore, the really short or tall drivers are not supported through the design of the cab in an adequate amount and have to compromise their driving posture.

The division of CAB interior at Volvo Group Trucks Technology is dedicated to develop new interiors for different truck models in order to improve truck drivers' working life. More specifically, they are interested in gathering information and investigating the internal and external parameters that lead the drivers to choose a specific sitting behaviour in different driving situations. Furthermore, they are interested to know the factors that cause the transition between those different postures.

1.2 Aim of the project

This thesis project should identify the key parameters that govern the driver's chosen driving postures. The focus will be on the internal arrangement of the driver's position (cockpit), in relation to internal and external parameters.

A parameter that influences the thesis project is the height of the participants. A variation of heights will be examined with an extra focus on the extremes (tall/short). There are various studies related to the average truck driver population and only little investigation on the above extremes. It is an assumption that those people will face more difficulties in driving comfortably and this will be investigated.

The more specific questions to be answered by this thesis are:

1. Which are the typical driving postures the drivers adopt?

2. Which are the major parameters that influence how the driver sits?
3. Which are the factors that cause transitions between significantly different categories of postures?
4. Which environments/ driving situations cause the most extreme postures?
5. Which are the problems that the short and tall drivers face while driving?

1.3 Delimitations

The study considers trucks within the Volvo-brand and no other type of vehicles. The model series that is used for the research, testing and evaluation phases is Volvo FH. This series is chosen as it can be used in different driving situations, under different conditions and it is designed to respect different anthropometric measurements, so that it can be driven comfortably by a wide range of drivers (Volvo 2015).

The target group of the study is the two main extreme cases within the truck driver population: tall which are taller than 1.85 m and short people that are shorter than 1.67 m, of both genders. There are many studies related to the average truck driver population and only little investigation on the above two groups of drivers, so this is an unknown area which could have interesting outcomes.

Since the target group is already limited (tall and short) and the truck drivers in general, are not easily available, the drivers that were participated in the studies were mostly internal drivers and employees from Volvo Trucks. Moreover, they were available to accomplish the activities that were designed for this thesis, in the planned timeframe, which is important for the smooth progress of the thesis.

1.4 Process overview

The project consists of three main phases which have been executed using an iterative process. Even though, each phase is described separately and thoroughly in this report, some of them have proceeded in parallel with others due to the structure and the complexity of the project.

Initially, a literature study was conducted which was used throughout the project as a supporting tool for analysing, composing and concluding in results. The three main phases are the three case studies that were held and founded this thesis work.

The first case study is the questionnaires, the second case study is the field tests with real truck and the third case study is the driving simulator study. The results of each case study and the comparison of the outcomes gave the final conclusions and design proposals.

1.5 Project Outline

This report explains the complete implementation of the project and is divided into main chapters conforming to the process of the project.

The first chapter introduces the project with background information. It also describes the purpose, goal and delimitations as well as the process.

In the theory chapter - chapter 2 - information about the trucks, the truck drivers and the most demanding driving situations is presented. Additionally, there is an introduction to the different driving components of the vehicle and the specific Volvo model that is used for the study. Findings from previous studies, regarding anthropometry, truck driver's health, sitting posture, comfort, vision, decision making and driving simulators are also analysed.

The third chapter presents the preliminary methods that are used, as well as how they were implemented into the beginning of the project.

Chapter four describes the first case study, the questionnaires. It includes the aim, method, results and conclusions that were obtained.

The fifth chapter presents the second case study, the field tests with real truck. It consists of the aim of the study, the methods that were used, results, discussion and conclusions.

Chapter six, describes the third and final case study, the simulator studies. It follows the same structure as the previous studies, including the aim, method, results, discussion and conclusions.

In chapter seven the general discussion takes place. Reflections and thoughts on the complete project can be found here and the discussion is concluded with recommendations of further work for completing that kind of studies.

The eighth chapter includes the conclusions of the entire project, as well as some design proposals that have arisen.

2 Theory

The following chapter presents theories that have been used in the thesis project. It covers several areas, ranging from the type of trucks, driving components and driving situations. The chosen theories formed the introduction of the theoretical part for this project.

Trucks Theory

2.1 The road haulage industry today

According to the European Commission (European Commission, 2014), road transport transfers 72% of all goods in inland transport in the EU, with an annual turnover of €300 billion and accounts for some 2% of the EU's GDP (Gross Domestic Product). Therefore, the road haulage is a sector that contributes to the growth of the economy.

There are regulations about the working hours the truck driver must follow. The non-stop driving must not exceed 4.5 hours and there must always be a break of at least 45 minutes during that complete period of time. The daily driving must not be more than 9 hours and during a week the driver must not drive for more than 56 hours. (European Commission, 2014; Commission, 2012)

2.2 Truck Categories

In general, almost every Truck brand has the following three types of vehicles: a truck series for long haul distances, a series for distribution and a series for construction, which cover different utilization cycles or a combination of them. According to the category the truck belongs to, the size, height and characteristics vary. The Global Transport Application report of Volvo Group (Report V.G., 2003) states that the trucks can be categorized in terms of utilization as "Stop and Go", "Local", "Regional" and "Long Distance".

Distribution trucks are used for transporting goods during a workday and they are usually smaller, so that they have manoeuvring possibilities (Dreijer & Wahnström,2014). These trucks could include the following cycles: "Stop and Go" cycle is characterized by a mean distance shorter than 0.5 km between deliveries or picking up goods. During the latter, there are transitions between stop and go, low speed and stationary state. "Local" cycle is characterized by a mean distance shorter than 5 km but longer than 0.5 km. Its main characteristics are many stops and low average speed. The "Regional" cycle has a mean distance between deliveries or picking up goods shorter than 50 km but longer than 5km. There is a combination of short and long distances between stops and those stops are usually clustered. (Report V.G., 2003)

Long haulage trucks include a large cockpit and cab, as they are designed for routes that last several days or weeks and as a result the cab is almost the driver's house for those days (Dreijer & Wahnström,2014).

To support longer stays inside the vehicle, the long haulage truck is designed to provide one or to beds and required storages for longer periods of living in the cab. The standard layout globally is to have the bunks arranged transversally behind the driver and passenger seats. At the same time there are length regulations that limit the total length of the vehicles allowed on European roads. This means that the total vehicle length has to be distributed between the vehicle cab and the load carrying superstructure behind it. As container and trailer sizes are standardized and there is a maximum allowed total vehicle length, total cab and interior lengths are also very much becoming industry standard among different truck manufacturers. There is in most cases an intrinsic packaging compromise between cockpit lengths and bed widths.

Long haulage trucks usually perform the "Long distance" cycle, which is characterized by a mean distance between deliveries or picking up goods longer than 50 km and it includes few stops, high average speed and long distances covered during each working period. (Report V.G., 2003)

Finally, construction trucks are used in rough environments, roads that are bumpy and put high demands on the driver to operate. (Report V.G., 2003)

For this study a specific series of Volvo Trucks was used. The selection of this series was done due to the possibility to be used in many different driving conditions and in different utilization cycles, so that varying options and situations can be examined through it.

2.3 Volvo FH series

Volvo FH is a range of heavy-duty trucks manufactured by Volvo Trucks. It takes its name from the first letters of the words "Front High". The first model was launched in 1993. Currently, the third generation of this series is in production. (Volvo 2015)

Volvo FH (Figure 2) is the truck series that was chosen to be used for this project, as it can be used in several different conditions and demanding situations, including almost all the utilization cycles that are mentioned before. (Volvo 2015)

According to Volvo, FH series provides maximum load capacity and at the same time comfortable conditions for the driver. Among others, it can be used for long-haul transportation of excavated materials and agricultural goods. This series is also used for carrying out rescue operations, infrastructure, public works and shipments of chemical substances, as it is safe in hazardous environments. At the same time, it is ideal for local and regional cycles. (Volvo 2015)

Figure 1, FH16 (Volvo web site)

2.4 Cab Interior

According to Volvo 2015, FH series is characterized as one of the most comfortable heavy - duty vehicles in the market. Huge research has taken place for this series, and the new FH includes many improvements, in its characteristics, providing the driver with even more comfort. The cab interior is presented below, in Figure 2. As someone can see, the interior is spacious, provides the driver with many opportunities and creates a friendly and cosy working environment, which is shown in Figures 2-3. (Volvo 2015)

More focus on the specific components that are going to be investigated in this study, will follow in the next chapter.

Figure 2, Volvo FH cab interior (Volvo web site)

Figure 3, Interior Details 6 (Volvo web site)

2.5 Driving components

Every vehicle has a unique cockpit in order to support the drivers and increase their comfort. It is important to create an environment that combines the driving components in a sufficient way and handle all the different variations of drivers' sizes. The cockpit of the truck consists of the pedals, instrument panel, steering wheel, seat and windows. Another governing part of the cockpit is the exterior components like the mirrors. In this chapter, Volvo's driving components are described and also the different adjustment possibilities they provide.

2.5.1 Pedals

The pedal system is a dominant part of the driving tasks and consists of two to three pedals. They are activated by the foot and include the accelerator, the brake pedal and the clutch pedal (that becomes rarer due to the increasing usage of automatic gear boxes). The accelerator is located at the right part and it controls the amount of fuel provided to the engine. The brake is also located on the right side. By using this pedal the driver can decrease the speed of the vehicle. The clutch is operated by the left foot and it is a subcomponent of an engine's transmission (Fatollahzadeh, 2006; Larsson & Persson, 2003).

2.5.2 Steering Wheel

The steering wheel (Figure 4) is an adjustable main steering device and it can be manipulated by the use of a foot pedal in Volvo FH. It is launched in two sizes with diameter of 450 and 500mm depending on the type of the truck. The driver can adjust its position over a vast range as well as angles between -5° and +15° by using the neck tilt function as shown in Figure 4. The position adjustments are both for achieving maximum comfort while driving, but also to facilitate getting in and out of the truck as it can be folded away forwards. (Volvo, 2015). The steering wheel consists of several switches like cruise control, audio and infotainment system as well as phone calls. The stalks are one on the left side for indicator and light functions and two on the right side controlling engine brake (retarder) and wiper system respectively.

Figure 4, Volvo FH steering wheel (Volvo website)

Volvo FH steering wheel

Figure 5, Adjustment rate of steering wheel (Volvo website)

The latest Volvo FH model is equipped with the Volvo Dynamic Steering. It consists of an electric motor, which is mounted on top of the hydraulic steering gear. Its purpose is to provide precise steering control in every situation and improve the manoeuvrability of the truck. It is designed in order to increase the stability at high speeds and to take away the physical effort while performing low speed manoeuvres.

2.5.3 Seat

The truck seat is designed to increase the comfort of the driver for short, as well as extended periods of time. It should minimize drivers' fatigue and position them in a proper location in order to reach the steering wheel, the brake and the accelerator pedals and the instrument panel controls (Fatollahzadeh, 2006). Also, it should provide the drivers with enough leg room and a clear field of vision from the opportunity to adjust the height and thereby changing the driver's head location.

Figure 6, FH Seat (Volvo website)

Today's seat is adjustable and the adjustments can be made both manually and electrically depending on variant (Volvo web site). It is composed of several features like adjustable back and shoulder rests, arm rests and lumbar supports in different levels. A fixed head restraint is included as well as heating and ventilation, variants with integrated seat belt and different surface materials (like fabric or leather in different colours), as shown in Figure 6. (Volvo web site; Larsson & Persson, 2003)

Driver seat in Volvo FH

The seat of the new Volvo FH model can be adjusted horizontally 24 cm and vertically 10 cm and it is developed for driving long distances for extended periods of time.

2.5.4 Dashboard

Almost all the instruments in the truck are located on the dashboard, as shown in Figure 7. The dashboard is designed in order to provide the driver with full control of the vehicle and allow variations of working postures. It also contributes to a comfortable driving position by increasing the reachability of all buttons, instruments and storages. The main components are the instrument cluster, the secondary display (providing access to e.g. radio as well as navigation) the switch control panels, the climate system components, the electrical centre and the wiring (Volvo web site; Larsson & Persson, 2003).

Figure 7, Dashboard of FH (Volvo group)

Dashboard in Volvo FH

The dashboard of the Volvo FH consists of an instrument cluster with several displays, control panels for various functions (like the climate system, entertainment system, light controls, etc.), a secondary information display (for information about radio, phone calls, orders, navigation, camera views, etc) and different storage facilities (like cup-holders or smaller compartments for bits and pieces). However, the dominant part is the instrument cluster. It encloses the speedometer, the tachometer and information about gear, I-Shift mode, cruise control and brakes. There is also a display at the left part of the speedometer which includes additional information like the level of fluids, the driver alert support, the load indicator and different error messages. Another part of the instrument cluster is the secondary display. It is located to the right of the instrument cluster and contains many features like the GPS navigator, the exterior vision cameras, the audio system, the phone and the dynafleet for handling transport orders.

2.5.5 Indirect Vision

Indirect vision is an even more significant aspect in a truck than in a passenger car, as large areas outside of the vehicle can only be seen by using mirrors (Figure 8) and cameras. Mirrors and cameras are used to obtain the required information of a specific field of view. They are used to continuously have a good view of the traffic situation and control complex vehicle movements especially during manoeuvring.

Figure 8, FH model mirrors (Volvo website)

Indirect vision of Volvo FH

The FH rear-view mirrors are designed to increase the area of vision on the driver side and on the passenger side while keeping obstructions to a minimum. They consist of main and wide-angle mirrors. In addition to this there are two close-up mirrors, one for the front and one for the passenger side. These help to show the areas closest to the truck otherwise impossible to see via the window openings. In addition to this up to four additional exterior cameras can be ordered and connected to the secondary information display.

Moreover, Volvo launched a radar system which helps driver to be aware of traffic approaching from behind. This device provides a warning if the driver engages the indicator to change lane and a vehicle is occupying the lane already. This is thereby also improving the safety to the driver in complex traffic situations.

2.5.6 Direct Vision

The driver obtains information of the surroundings by utilizing the direct vision through window openings, Figure 9. Those openings are either the side windows, the windscreen or the rear windows.

The windows are separated by A and B-pillars. The A-pillars separate the windscreen from the side windows on each side, they are positioned on the left and the right sides of the cab and support the cab roof. B-pillars are located behind the doors on each side, they support the roof and form the border to the rear side windows. The rear side windows as well as rear window are optional according to truck model and cab variant.

Figure 9, Windscreen, side windows and mirrors of FH model (Volvo website)

Direct Vision of Volvo FH

The Volvo FH has upright A-pillars for bigger windscreen and side windows and increased interior space. The position of the A-pillars is also improving the direct vision from inside the cab as well as the positioning and vision via the different mirrors.

2.6 Driving Situations

Professional drivers adapt their posture according to the driving situations and the task they have to accomplish. The main driving situations are distinguished in three categories: driving in high way traffic, in dense city traffic and performing low speed manoeuvring.

I. Driving in high way traffic

Figure 10, Driving in high way (Volvo website)

By driving in high way traffic, Figure 12, drivers operate less number of deliveries and a typical characteristic is the high average speed. Moreover, they spend less than 50% of their operating time and less than 20% of the driven distance in urban areas. Statistics show that long-haulage vehicles cover between 80,000 and 400,000 kilometres per year. The variation comes from several factors like the service frequency, the operating time and the type of services (Karlsson, 2004; Report V.G. ,2003).

In long distance traffic the drivers tend to sit in a relaxing position and sometimes they move their seat backwards and tilt it. The drivers use the controls and the pedals very rarely and they choose a more "passive" way of driving. They also make small adjustments in the cab like changing the angle of the backrest or moving the steering wheel down in order to increase their comfort for longer period of time. (Larsson & Persson, 2003)

II. Driving in dense city traffic

Figure 11, Driving in the city (Volvo website)

Dense city driving is always a challenge with crowded streets, narrow alleys and many stops as shown in Figure 11. The drivers accomplish a lot of deliveries or pick-ups of goods and they typically cover short distances among 15,000 and 40,000 Km per year. Furthermore, they spend more than 20% of the distance and more than 50% of the operating time in urban areas (Karlsson, 2004; Report V.G., 2003).

Driving in city traffic demands a lot of effort and the drivers should be concentrated on the surroundings. They use the mirrors a lot and need a better overview of the close-up area. Moreover, they sit more upright in order to be aware of the objects in the road environment. (Larsson & Persson, 2003)

III. Performing low speed manoeuvring

During the performance of low speed manoeuvring the drivers use the steering wheel a lot and utilize the mirrors and the windows in order to achieve clear vision towards the front, side and rear. An example of low speed manoeuvring occurs during parking while the vehicle moves slowly and changes direction a lot. The drivers should be able to manipulate the vehicle in narrow areas and they should be really precise and focus on the actual manoeuvring as well as on the nearby surroundings (Report V.G., 2003). They also use main driving controls and other controls a lot because they are related to functions of both getting the vehicle into the right place as well as loading/unloading the goods. They need to be alert and for this reason they tend to change position very frequently to obtain information for the surroundings.

3 Preliminary Methods

This chapter outlines the preliminary methods that were used, and how these were implemented in the beginning of the project.

3.1 Planning

Planning and structuring were conducted during the first phase of the project. There were a number of important steps and goals that were identified and explained in a planning report, which was also prepared in this phase. Additionally, a Gantt Chart was created to provide a better overview of the deliveries and the different phases. Respectively, a detailed plan with the weekly/monthly meetings with the supervisors was also created to structure the most important activities.

3.1.1 Gantt Chart

A Gantt chart is a simple tool that presents the activities against time. There is a list of the activities on the left side and on the top part of the chart there is a timeline. Each activity or task is illustrated by a horizontal line and its length presents the duration. It is a good way to overview and visualise the various activities, their starting point and the period of time are set to last. Additionally, it is a really useful tool to present the activities that are accomplished in parallel (Ulrich & Eppinger, 1995)

In this thesis project, Gantt Chart contributed to a sufficient structure of the entire project and an optimisation of the time. (See Appendix I)

3.2 Data collection

The aim of this phase was to broaden the knowledge and gather information from users and relevant theory. The data was analysed by utilizing several methods. The methods provided the project with theoretical knowledge about various areas and highlighted user needs and demands. In order to gain more knowledge about the factors that influence the comfort and the driver's postures, an extensive user study was executed. It was introduced with a survey including a detailed questionnaire and completed with observations and interviews by using results from field studies and from the driving simulator.

3.2.1 Literature Studies

A literature study is carried out in order to get more knowledge and insights for a specific field (Bohgard, M. et. al, 2009). The relevant literature can be articles, books, previous master thesis reports, research studies and many other written documents that can be found online or in print publications.

In this project, literature studies were mostly used in the early stages and the main sources of them were articles and books. The deeper search was held to get background information and Knowledge for the truck driver's health, their vision, their postures and their anthropometry.

3.3 Observation

Observations are a useful tool to understand how people act and behave in an actual situation. It is a good way to get more knowledge regarding things that the users might not be aware of. However, sometimes it is difficult to achieve natural behaviour if the users are informed about the study that is being held (Bohgard, M. et. al, 2009). During this method, observers can take notes, record the participants and it may be possible to use videotaping.

Observations were used in almost all the stages of the project in order to get a broad knowledge of the drivers' behaviour and the factors that influence their comfort and cause transitions between significantly different categories of postures.

3.3.1 Field Observations

Field observations are used in a project as a comparison between the results of the literature studies and the research. Nielsen (1993) argues that field observations increase the validity of the tests as many users perform tasks in their own unique way that cannot be tested in a planned laboratory experiment. Thus, the purpose of this type of observations is to understand better how the users behave in natural conditions without imposing constraints. To gather inspiration and experience of current truck cab solutions, a couple of driving trials was carried out. During week 5, short rides of about 20 minutes were held, using competitor vehicles available at Volvo for accomplishing competitor studies. The vehicles that were used for these short routes were DAF XF and Mercedes Actros. These unstructured observations of various brands were done mainly in order to achieve a familiarization with trucks, since none of the group members had ever been inside a truck before. Also, it was helpful to see what exists on the market and what could potentially be implemented so that driving comfort will increase.

Later, during week 9, an organized route of almost 2 hours driving was arranged, so that a focused observation could be held. The driver belonged to the tall population (1.90 m) and the truck that was used was a Volvo FH12. During the test drive, photos were taken, in a non-disturbing way as it is shown in figures 12 and 13. This test drive contributed to identifying some basic postures that the driver adopts, if the driving time affects the postures and which are the main obstacles for a tall person to feel comfortable inside the cab.

The objective of these initial test drives were to gain real life experience of trucks, and understand how it feels driving this type of vehicle. These test drives contributed also to understanding the complicated functionalities that are used in trucks and acquire knowledge to be able to design relevant upcoming studies with professional drivers driving the same truck as well as in the driving simulator.

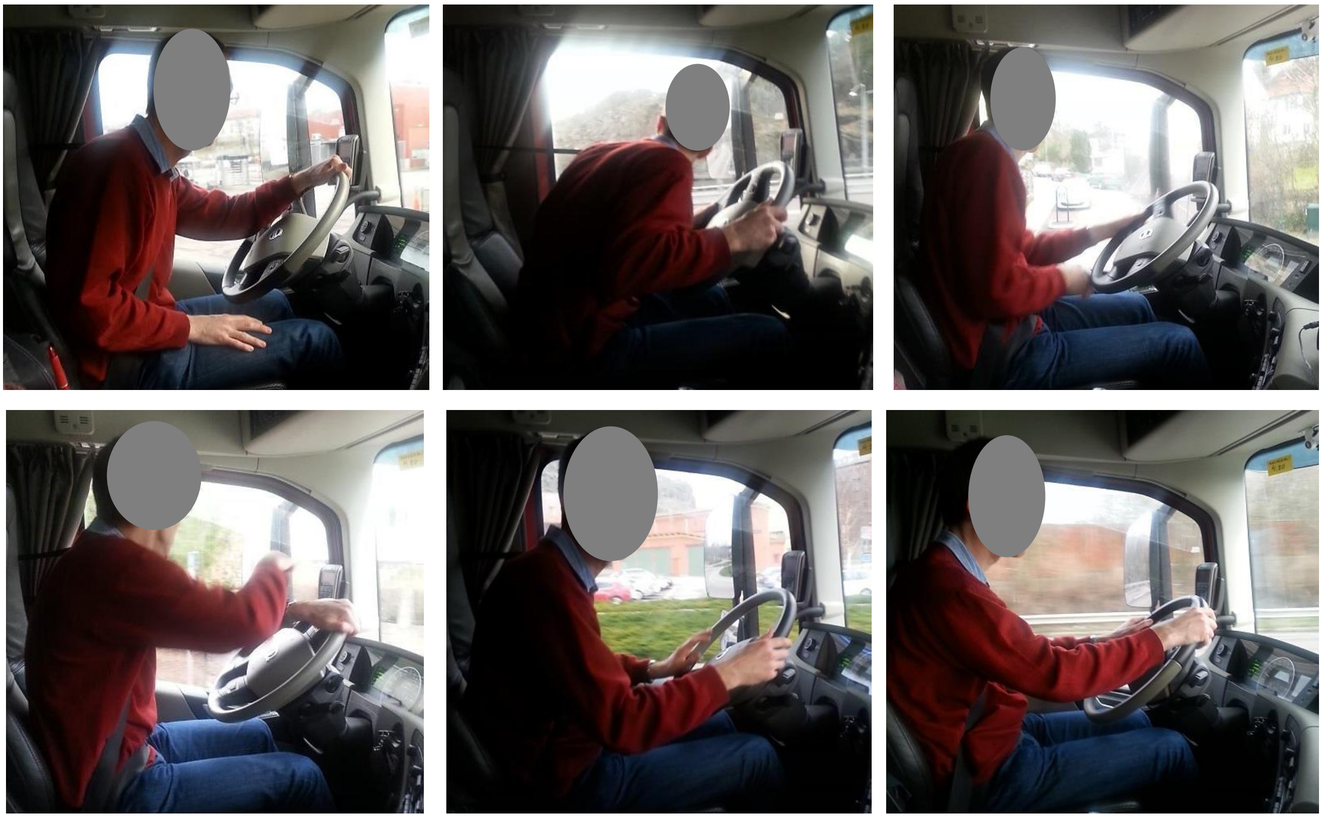


Figure 12, Posture observations

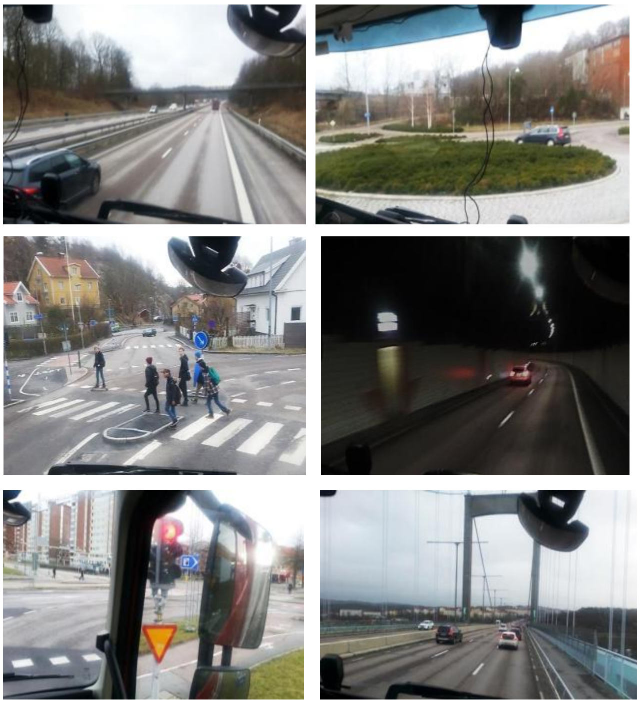


Figure 13, Driving conditions-driving in high way, roundabout, tunnel, bridge, residential area

4 Literature studies

The following chapter presents the literature studies of this thesis project. It covers several areas and contributes to get background information and Knowledge for truck driver's health, their vision their anthropometry and their posture. The literature studies formed the main theoretical part of this project.

4.1 Truck Drivers' Health

In ergonomics, force, repetition and posture are the three most common risk factors for injuries while working. OHSCO (2007) The force describes the amount of effort made by muscles, and the type of pressure as a result of different activities. Repetition describes the number of the tasks that are performed repeatedly, with few breaks for rest. Posture is the position of the body during an activity.

OHSCO (2007) distinguishes postures in two categories: static and awkward. Awkward postures refer to body positions that require constant movements and changes. On the other hand, static postures refer to the body positions that are adopted for a large period of time (OHSCO, 2007). Sitting is regarded as a static posture and is an important part of several working environments as well as professional drivers' working life. Among the driving postures, some postures are better than others because they respect the different driving tasks and also minimize the musculoskeletal problems (Reed, 1998).

4.1.1 Musculoskeletal disorders

Seated postures that are held by professional drivers are considered as potential factors for back pain and musculoskeletal disorders (Robb & Mansfield, 2007). Those musculoskeletal disorders involve pain in the spine, the low back, the shoulders and the neck (Schneider and Ricci, 1989; Magnusson, Pope, Wilder, & Areskoug, 1996).

Furthermore, there are reports which claim that truck drivers also suffer from pain in lower extremities like thighs, knees and feet (Osvalder, Utriniain, & Dahlman, 2003). Figure 14 represents the body parts where truck drivers usually experience pain. Especially, long-haul drivers have often been associated with high prevalence of musculoskeletal pain due to the poor postures. The effects of these postures in some types of trucks are linked with neck and low back pain (Massaccesi, Pagnotta, Soccettia, Masali, Masieroc, & Greco, 2003). Moreover, in several cases long-haul drivers mix long periods of inactivity with sudden quite hard work of loading/unloading which also forms a reason for the occurring problems.

4.1.2 Low Back pain

Among the various musculoskeletal disorders that are mentioned in reports, there is comprehensive reference to low back pain. Data gathered in the self-reported musculoskeletal problems among professional truck drivers show that the majority of truck drivers experience low back problems. A study performed by Gyi, D. E., & Porter, M. J. (1999) shows that it is more possible for people who are exposed to driving over 4 hours per day to suffer from low back pain. (Kyung, Nussbaum, & Babski-Reeves, 2008; Van Der Beek, Frings-Dresen , Van Dijk, Kember, & Meijiman, 1993; Magnusson, Okunribido, & Pope, 2006; Gyi D. E. , 2012)

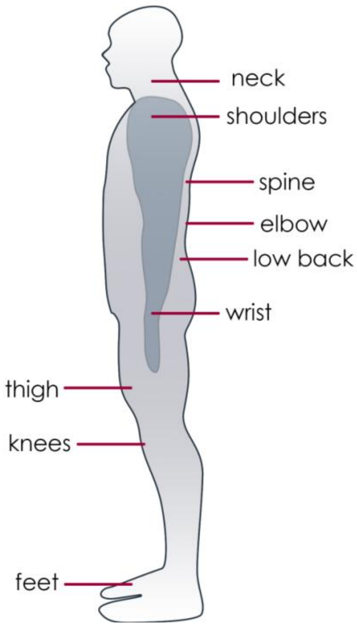


Figure 14, Body Parts in Pain

4.1.3 Factors that influence driver's health

The dominating factor which influences driver's health status and causes the musculoskeletal disorders is their working conditions. Those conditions include prolonged sitting, poor postures, exposure to whole-body vibration and noise (Van Der Beek, Frings-Dresen, Van Dijk, Kember, & Meijiman, 1993; Van der Beek & Frings-Dresen, 1995). Furthermore, the arrangement of the cab interior and components, as well as poor atmospheric conditions inside the cab, contribute to the generation of health-problems (Gobel, Springer, & Scherff, 1998; Massaccesi, Pagnotta, Soccettia, Masali, Masieroc, & Greco, 2003; Osvalder, Utriniain, & Dahlman, 2003). Besides the working conditions, the task of driving involves also muscular effort which loads the spine to varying degrees that could lead to fatigue of the musculoskeletal system. The driver puts a lot of effort to manipulate the vehicle and take control of the steering wheel, the brake, the clutch or the reversing and as a result different forces act on the body and load the spine with extra pressure. However, there is no evidence in the literature that these types of forces and effort could lead to severe injuries or increase the musculoskeletal symptoms (Gyi D. E. ,2012)

Truck drivers are also exposed to other non-driving risks such as heavy inappropriate manual lifts, stressful work or lifestyle risks like unhealthy diet, insufficient exercise, smoking and psycho-social alienation (Sundström, 2003). Drivers' way of working and living is more irregular compared to other jobs. For instance, the long-haul drivers put a lot of effort and they exposed to risks when they are not driving and struggling with loading/unloading goods and lift heavy goods manually. Moreover, they present high levels of stress, especially when they drive in dense city traffic or poor road conditions. They also tend to eat irregularly because of their schedule or because they want to "break" the monotony of long journeys (Fatollahzadeh, 2006). Furthermore, truck drivers spend a lot of time travelling alone and they have little contact with colleagues just during the breaks for rest. This leads to an increasing risk of psycho-social alienation. All the aforementioned factors have a remarkable effect on drivers' performance and well-being and they can also influence different parts of the body like heart, musculature, joints and sensory organs (Fatollahzadeh, 2006).

4.2 Anthropometry

The measurements of human body dimensions are essential when designing products and workplaces. The arrangement of a workplace and the location of different components and controls are determined by the potential users and their preferences. Thus, it is crucial to design a workplace that suits to a variety of body sizes, considering the size of the trunk, arms and legs, as well as the postures and movements that are necessary for efficient work.

In the same way as each individual has his/her unique anthropometrical characteristics, professional drivers have also body sizes that vary within a wide range. This range influences their perceived comfort and therefore their performance. (Fatollahzadeh, 2006). Factors that influence the variation of the anthropometric characteristics could be the age, gender, ethnical background, social class, occupation and nutrition. Some of those factors that are relevant to the study are going to be analyzed further.

4.2.1 Gender

Among the other factors, gender can be also perceived as a main reason for variation in body size. In general, the differences between the two genders are depending more on biological structure of the individuals (Larsson & Persson, 2003). Although, men's measurements all exceed women's, women tend to have longer legs and wider hips. On the other hand, the lengths of the upper and lower limbs are longer for men and the female have shorter torsos compared to male according to internal studies of Volvo). Figure 15, represents the difference between man-woman in a driving posture based on the internal data of Volvo.

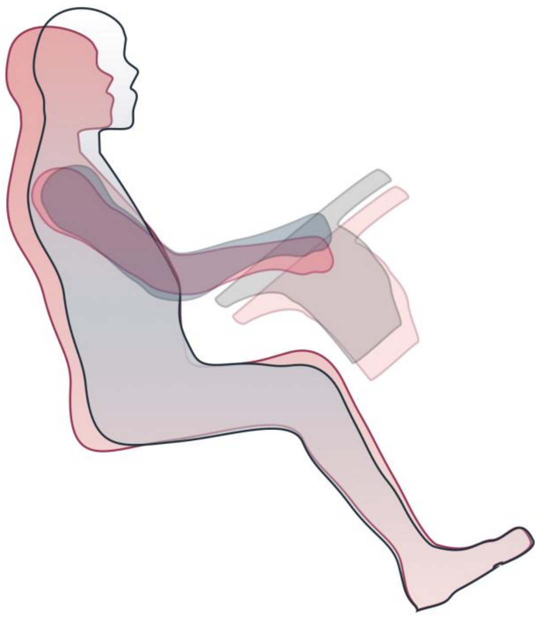


Figure 15, Man (grey) – Woman (pink) Driving Posture difference

Another example of the main differences between the genders is that female drivers have longer legs compared to male with the same height and as a result they prefer to seat significantly more rearwards. Hence, the main impact for the female drivers' eye point is lower and behind of the corresponding eye point of male drivers (internal Volvo).

4.2.2 Extreme Dimensions

In general, many problems have been reported during driving, resulting from specific anthropometric characteristics. There are several issues and driving situations in which designers should take into consideration those characteristics. The range of attainable postures is largest for people who are close to anthropometric means and smallest for the rest. There are many examples of people who belong to extremes and they can have a hardship to or even be unable to drive specific trucks (Reed, Lehto, & Schneider, 2000).

Most of the reported problems increase the need for further examination of the extremes and the barriers they face during driving.

Short drivers with short lower extremities will require a forward seat position in order for the feet to meet the pedals. This position moves the torso close to the steering wheel which can put extra requirements on how the steering wheel can be adjusted except from that there might be problems of feasible seat positions. An aggravating problem might occur if the same shorter driver is also obese. This means that the stomach is taking up more space which puts additional restrictions to how far the steering wheel can be brought towards the torso. Moreover, this can also be linked to that the field of vision gets limited by forward vision restrictions.

For tall drivers, the range of rearwards seat-track limits the hip position and their possibility to move more backwards (Reed, 1998). Longer legs can find room either by sitting further back or higher up. If the seat cannot be moved rearwards or the driver cannot sit higher due to limitations to the vision field, the posture becomes compromised.

According to the above issues and limitations, this study focuses on the two extreme cases of people's anthropometric dimensions, short and tall drivers.

4.2.3 Anthropometric measurement of tall and short drivers

It is important for the truck companies to design a workplace that meets the needs both of the average population and the extremes. For this reason there will be an extensive study on the needs of the short and tall drivers. Therefore, the anthropometric measurements correspond to drivers whose sizes are lower than the ones that belong to 5th percentile and higher than the ones that belong to 95th percentile population. However, it was important for the Thesis project to compromise and change the height limits for the target group since those limits made the access to the drivers more difficult and it was essential avoid inadequate results. Instead of 1.67 m, 1.70 m was set as the upper limit of the short drivers' height and 1.85 m was the lower limit for the tall drivers' height.

Table 1 lists the anthropometric measurements that are of interest when designing a truck cab that increases the comfort of the user. It represents the measurements of the truck driver population according to surveys that were accomplished on behalf of Volvo Truck Corporation. For the purpose of the master Thesis project, it was essential to focus on stature, knee and arm measurements disguising them in relation to the gender.

Table 1, Anthropometric Measurements

Dimensions	Female: 5th Percentile	Male: 5th Percentile	Female: 95th Percentile	Male: 95th Percentile
Stature with shoes	151 cm	167 cm	176.3 cm	190 cm
Sitting height	80.4 cm	85.8 cm	92.2 cm	97.8 cm

Knee height, sitting	48.7 cm	52.3 cm	57.1 cm	61.5 cm
Arm length	65 cm	71.5 cm	75.6 cm	83.8 cm
Shoe length	25 cm	28.5 cm	30.3 cm	33.4 cm
Weight	62.6 Kg	72.1 Kg	126.1 Kg	146.4 Kg

4.3 Sitting Posture

4.3.1 Sitting posture – an individual matter

The selection of a sitting posture inside a truck varies a lot from one person to another and both Fatollahzadeh (2006) and Reed (1998) claim that this depends on the individual needs each driver has. Accordingly, Sundström (2003) mentions that each driver, when choosing a specific sitting posture, has the main scope to achieve a comfortable position for the different parts of his/her body.

Consequently, this selection is highly dependent on anthropometric measurements, personal preferences and habits. However, the most important parameter that affects the selection of a sitting posture is that the driver needs to be able to have access to the pedals, the steering wheel and the seat, at the same time.

Previous studies have shown that there is a pattern in driver's posture selection during driving. According Sundström (2003), all drivers tend to have one or two favorite postures, which they keep for the majority of their working hours.

Osvalder, Utriniain, & Dahlman (2003) proposed a method for posture coding that includes seven sagittal back positions and three lateral back posture classes, presented in Figure 16.

When a driver adopts a certain posture, gradually he/she changes it and does small repositioning movements in order to feel more comfortable. (Karlsson, 2004; Sundström, 2003; Osvalder, Utriniainen, & Dahlman, 2003) This alternation is smoothly done and extreme position changes have not been identified.

The use of seatbelt is an inhibiting factor for having significant changes of posture. (Moric, Rexfelt, & Utriainen, 2003) There is difference if a seat belt is mounted on the seat or if it is mounted on the B-pillar. The one mounted on the seat will provide less limitations as the belt follows the seat when it is adjusted. The belt on the B-pillar on the other hand will result in bigger problems, as the seat gets into positions that do not match well with where the belt is installed. The worst thing that can happen from this is that the driver stops using the belt.

However, drivers tend to change their posture often in the beginning of each journey, thus for almost 15 minutes they adjust their position continuously in order to achieve the most comfortable position. It is also identified that drivers' need to change their posture more often, gets more intense after sitting for a long period. (Moric, Rexfelt, & Utriainen, 2003; Sundström, 2003)

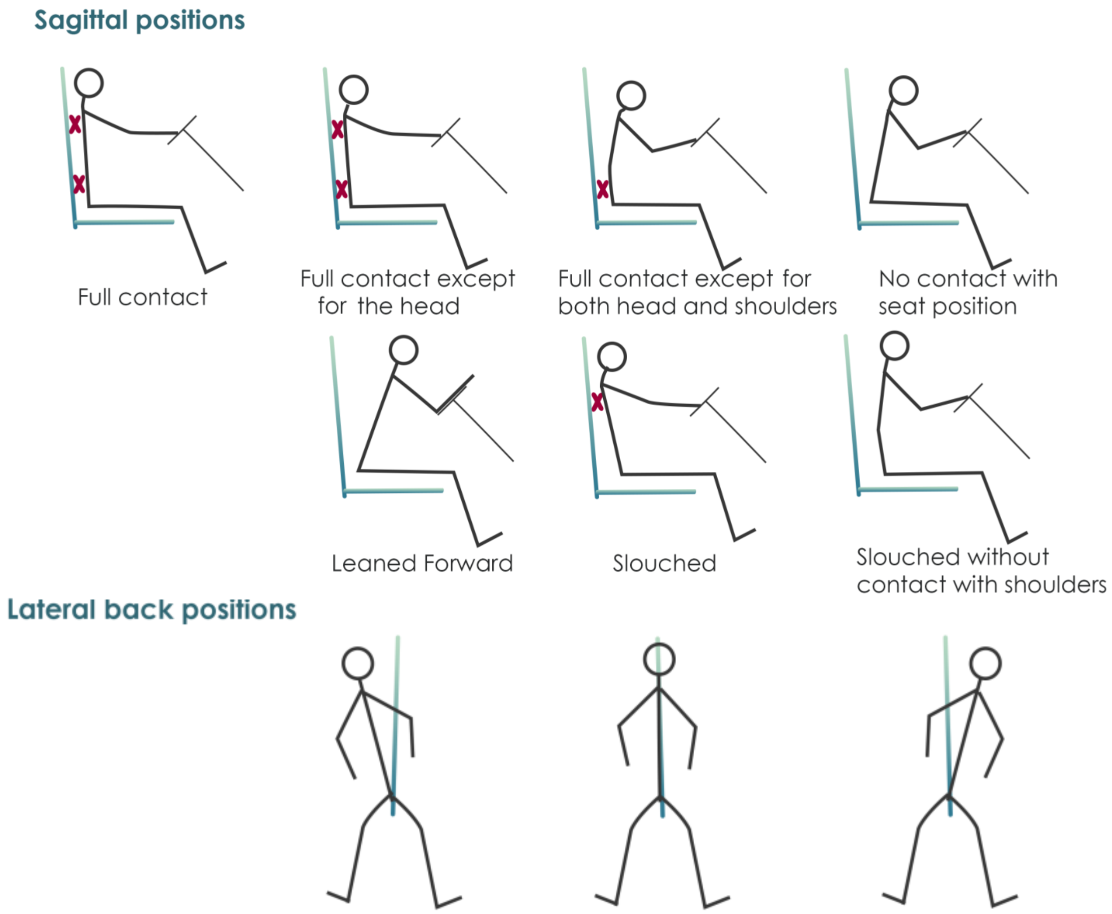


Figure 16, Sagittal sitting position (Osvalder, Utriniain, & Dahlman, 2003)

4.3.2 Is there an ideal sitting posture?

The quest for an ideal sitting posture design is a question that is addressed in many studies. Is it possible to achieve it, or could the truck be designed so that the driver is forced to sit in a certain ideal way and be happy with it? As mentioned before, individual factors play the most important role when it comes to the selection of a sitting posture, and having this as a fact it is quite difficult to design or predict an ideal sitting posture for everyone.

Dynamic sitting is what should be promoted through the design of the seat. Moric, Rexfelt, & Utriainen (2003), Osvalder, Bligård, Dahlman, & Sjöberg 2005), Callaghan & McGill, (2001) and Gyi D. E. (2012) claim that a locked sitting position, even if it is thought to be ideal, in the end is harmful for the body. The ideal sitting posture is a variable position, which can be achieved through a seat that encourages and allows a variety of postures.

The procedure that the driver selects his/her posture may be considered as simple, but in fact it can be the exact opposite. It is a complex procedure, which takes into consideration several parameters (Fatollahzadeh, 2006). Sundström (2003) claims that only half of the posture changes are related to the seat, while the other half are caused by the actual driving task. Reed (1998) states that an inner process takes place inside the driver's sub consciousness, which controls the selection of a specific posture while driving. Fatollahzadeh (2006) explains this procedure of selecting a driving posture, as a strategy which is affected by behavioural and environmental factors, in relation to the actual task and the driving components.

4.3.3 Parameters that influence the sitting posture

The parameters that influence the choice of the truck driver's sitting posture are both internal and external. According to Reed (1998) and Gyi D. E. (2012) the driver should have the control of the vehicle by having a good view of the outer environment, and should be able to use/reach the pedals and the steering wheel, while sitting. Gyi D. E.(2012) claims that a non-ergonomic design of the truck and the components within the cab leads the driver to select poor/ inappropriate postures that result in health issues. Therefore, although the driver usually wants to change posture in order to alleviate the parts of his/her body that are not comfortable, in the end the selection of those inappropriate postures leads to problems instead of relief (Kyung, Nussbaum, & Babski-Reeves, 2008).

Although driving is a demanding activity, which requires attention and concentration, the drivers tend to be involved at the same time with other, secondary activities. Those activities are a reason to make them change their posture while driving. The new adopted posture does not often increase their comfort, but it is a way to handle the other activities at the same time (Young, Regan, & Hammer, 2003; Ito, Uno, Atsumi, & Akamatsu, 2001). Some examples of those activities are the following: talking on the phone, adjusting the radio, air-conditioning system, devices or controls that are located in the dashboard. Eating, drinking and smoking are also some of the activities that take place inside the cab. Moving an object, searching for something, or talking to other occupants in the vehicle, are also realistic situations that could happen during a journey (Stutts, Reinfurt , Staplin, & Rodgman, 2001). In summary, the situations that the driver has to handle inside the truck and that influence his/her sitting posture, are related to the technology, to other passengers and to some of his/her biological needs (Rospa, 2007).

In the external environment, factors that can affect the posture of the driver are other vehicles, cars, trucks, motorcycles, bicycles and pedestrians (Rospa, 2007). Overtaking, braking, roundabout driving are also some events that take place in the outer environment, which affect in a huge amount the sitting posture of the driver (Sundström, 2003). Sundström (2003) mentions that the traffic conditions are a severe reason for a driver to change posture. Therefore, in city driving the drivers need to be more alert and be able to identify everything that is in their nearby field of vision. As a result, they tend to sit more upright, adopting a tilted forward posture. The same applies to loading/unloading procedure. Karlsson (2004) concludes that the driver adopts a more comfortable – leaning back position if he/she does not have to operate with controls inside the truck or if he/she has not to be really careful in the environment he/she drives. The loading/unloading procedure is more complicated and drivers tend to lean left side, while at the same time they do not use the complete functionality of the backrest.

4.4 Comfort

4.4.1 The perception of comfort

Truck drivers spend lots of hours sitting in the truck's cab. Even the newest cabs have some problematic areas, which are mainly related to the restricted available space for the driver. However, providing the drivers with a comfortable environment is crucial since this is their working environment (Sundström, 2003).

Comfort could be divided in 6 categories according to Buti (2001) who perceives comfort mostly like a sensorial concept. Vibrational comfort is related to the effects of mechanical vibrations which are caused both by the engine and the road and are transferred through the suspension system (a combination of the tyres, the chassis suspension, the cab suspension and the seat suspension in a truck). Acoustic comfort includes the sounds caused by the mechanical parts of the vehicle (mainly engine and transmission) and the movement of the vehicle itself (including such things as tyre noise and wind noise). Tactile comfort has to do with the surfaces of the interior and the perceived quality of them. Comfort of vision concerns the quality of shapes and colours. Thermal comfort is connected to the quality of the climatic conditions within the cab interior and the thermal sensations of the surfaces that the body is in contact with. Finally, there is the comfort related to smell, which is related to the odours of materials, surface treatments and the occupants within the cab.

By providing the drivers with a comfortable cab, the adoption of awkward postures will be reduced and the drivers will perform with the maximum of their possibility (Kuijt-Eversa, Krause, & Vink, 2003). However, there is also the risk of providing the drivers with too much comfort, which could result in drowsiness (Moric, Rexfelt, & Utriainen, 2003). There should be a balance between those two factors, so that the drivers are effective in their work, but at the same time feel comfortable. The workspace should be ergonomically designed, promoting at the same time the selection of a posture that leads to alertness and not to drowsiness.

4.4.2 Discomfort

Discomfort causes negative feelings, fatigue, pain, tiredness, numbness and according to some people this could be a main reason behind severe road traffic accidents caused by trucks (Sundström, 2003; Fatollahzadeh, 2006; Michel & Helander, 1994). Kong (2010) claims that discomfort rises as time passes and as a result, in the end of a workday discomfort will be in its peak.

Vergara & Page (2002) concluded that great changes of the drivers' sitting posture, are an evidence of discomfort and that the main reasons of the growth of discomfort are lordotic postures with forward leaned pelvis and immobility. Sundström (2003) discusses also the changes of posture and noticed that the frequent change of posture of some drivers is related to the use of artefacts inside the cab. However, only a few times there was an actual need for the drivers to use the specific artefact. Most of the times there was not a reason to using them, according to the observer. This could be explained as the drivers' try to compensate the feeling of discomfort by activating themselves with using an artefact. Therefore, it could be said that discomfort leads the drivers to adopt a compensatory behaviour inside the truck, in order to overpass the discomfort.

When it comes to discomfort rating and identification of discomfort, this can be controversial, since the drivers do not often connect their disorders with the sitting itself and the discomfort feeling (Osvalder, Utriniain, & Dahlman, 2003). Gyi & Porter (1999) mention that at least 2 hours of testing is required to estimate discomfort levels, that is to say fatigue in sitting postures. Furthermore, Hanson, Sperling, & Akelsson (2006) claim that drivers prefer not bilaterally symmetric postures, thus comfort ratings should not be obtained for paired body parts.

4.4.3 Building a comfortable cab

Moric, Rexfelt, & Utriainen (2003) refer to some factors that contribute to a cab being characterized as comfortable. The most significant part is the seat, which should be adapted to the vehicle's vibrations, providing ergonomic support and being able to be adjusted according to each driver's anthropometry. Wakefulness should be achieved, by a seat that allows variation and movement. Furthermore, the environment inside the cab should be pleasant and a neutral temperature should be easily achieved. Finally, the cockpit should amplify the safety of the driver.

Kolich (2007) agrees also that the seat is a crucial factor for the perceived comfort and addresses the issue of the seat comfort as a multi-dimensional issue, including vehicle/package factors, social factors, individual factors and seat factors. These factors affect the subjective perception of automobile seat comfort. Vehicle/package factors are the seat height in relation to the eye point, the pedals and steering wheel position, the head, knee and leg room and the transmission type. Social factors could be the vehicle brand and the purchased price of the vehicle. Individual factors are the demographics, anthropometry, culture and posture. Finally, seat factors are stiffness, geometry and contour, breathability and styling.

Osvalder, Bligård, Dahlman, & Sjöberg (2005) connect the perception of comfort to the psychology of the driver, taking into consideration factors like aesthetical appearance, manufacturer and marketing. Thus, drivers may perceive a market leading seat or a very aesthetical seat which is more luxurious than the average, as a reward because their employer appreciates their work.

Kyung, Nussbaum, & Babski-Reeves (2008) claim also that the role of the seat in the perceived comfort is crucial. It is not an exclusive parameter, but drivers have continuously more expectations for their vehicle's comfort and thus producers try to invest on providing really comfortable seats. Most seats are designed having many features which allow even the long – term sitting to be ergonomic. Moreover, customization can be achieved for the lumbar curvature, the backrest angle, head rest and air suspension that adapts to body mass (Osvalder, Utriniain, & Dahlman, 2003). Therefore, driver seats are already enough comfortable and ergonomically designed and as the adjustable features/opportunities increase, it is more possible that everyone could be satisfied by being able to adopt comfortable postures while driving (Gyi D. E., 2012).

Sundström (2003) concluded that the most uncomfortable factors in the driving environment are the cramped cab space and the upright driving posture. However, Gyi D. E. (2012) and Malczyk, Müller, Eßers, & Hänsel (2013) agree that drivers that belong to the extreme anthropometric dimensions are those that usually have to compromise their posture in order to fit into many vehicles and feel mostly uncomfortable. For example, short drivers have to adopt a more stretched posture in order to reach the pedals while they maintain a functional distance to the other controls. This apparently results in dissatisfaction and discomfort over longer working hours.

4.5 Vision

Visual demand is a significant factor that influences the driving posture. Vision restriction or bad field of vision can make drivers to change their postures constantly. The effects of them on driving posture highlight the way that drivers balance their comfort and the physical requirements of their task. Vision restriction is highly associated with parameters like eye location and seat position (Reed, 1998). The problem of the bad field of vision seems to be more present in situations like driving in the city and performing manoeuvres where lateral and rear view vision is more frequent and crucial (in the case of trucks strongly supported by different types of indirect vision devices like mirrors).

4.5.1 Parameters that increase vision restriction

The driver obtains information for the surroundings through windows, mirrors and displays. According to the European type of truck, the cab is located on top of the engine and this position increases the lack of vision to surroundings that are close to the truck. There are also three other parameters that can increase driver´s vision restrictions. The first is identified when the driver's visual field is blocked by obstacles. An example can be the objects that the driver places on the dashboard and occupy his/her attention instead of identifying pedestrians while driving in the city. The second type of distraction occurs when the driver is focusing on another type of visual information such as on the built-in climate controls, navigation device or audio equipment. The third type is related to the road environment. For example, the driver focuses on the best way to reach his/her destination and he/she does not pay attention on the current road conditions (Ito, Uno, Atsumi, & Akamatsu, 2001). Another substantial parameter that can influence driver postures is attempts to overcome the blind spots around the vehicle when the vehicle driving forward or when controlling complex vehicle situations, e.g. manoeuvring (Danielson & Hocke, 2013).

4.5.2 Improvements

A priority for a truck company, in order to achieve better field of vision, is to create an operating space with high optimal visibility (Osvalder, Utriniainen, & Dahlman, 2003; Reed, Lehto, & Schneider, 2000). The high optimal visibility is achieved by providing the driver with clear forward vision and vision to the left and the right. Another parameter that can maintain the high levels of visibility is the rear view and the close up vision. In trucks the chosen positions for indirect vision devices like mirrors in relation to the window openings become a key.

Recent studies indicate the potential benefits of replacing the traditional mirrors with camera-monitor systems in order to enhance rear view vision while reducing blind spots (ISO, 2013; Danielson & Hocke, 2013). However, utilizing a similar system requires extra adjustments to the entire visual information of the cab and increases the challenges for the company (Danielson & Hocke, 2013).

4.6 Decision Making

4.6.1 Driving as a task

According to Fatollahzadeh (2006) driving is a multidimensional, very complex and tiring task that requires the driver to be completely alert and concentrated, so that he/she is able to perform safely and effectively. Experience is of course crucial as a factor to secure high quality operations, but other factors such as knowledge and education should not be neglected. There is not a particular regulation concerning a method which has to be followed by the drivers, as being correct or incorrect. As a result, the task could be characterized as flexible. The truck driving job could be characterized as monotonous but at the same time it is autonomous and multi-functional. In every action the driver has to perform, a compromise decision has to be obtained which includes a vast amount of responsibility. It is logical that the aforementioned characteristics of the driving task create vague and uncertain circumstances, under those the drivers have to perform. The high levels of responsibility create physical and psychological workloads.

Tretten (2011) states that the primary task the driver has to accomplish is to gather visual information from the environment, to process it, and finally to react manually so that the vehicle continues moving safely on the road. The majority of those tasks, such as keeping speed, are usually performed with insignificant effort, almost automatically (De Waard, 1996). On the other hand, secondary tasks may be equally demanding for the driver, as the driver's attention is highly required. Some examples of secondary tasks are collecting information about the truck's performance and condition, acting in relation to the driving conditions, creating comfortable conditions or overtaking other vehicles (Gellatly, 1997).

4.6.2 Factors that affect performance

According to Moric, Rexfelt, & Utriainen (2003) there are four factors that influence the driver's mental performance. These factors are sitting, vibration, sound/noise and temperature. However, the relation between those parameters is not that clear, due to the complexity of the area. Some parameters are not easy to control continuously in an experiment and they are also perceived in a different way from individual to individual. As a result, the studies that have been accomplished provide varying results. There are also additional characteristics which should be taken into consideration when testing the above. The individual truck driver's perception, memory, way of thinking and linguistic processes are some of them.

A driver's mental performance could be affected in two ways. Either the driver feels too comfortable, which combined with a monotonous task easily causes drowsiness and idleness (mental underload) or the driver feels too uncomfortable because of the sitting posture or the vibration as well as other environmental factors and this could cause distraction from accomplishing other more demanding mental tasks (mental overload). (Moric, Rexfelt, & Utriainen, 2003)

As mentioned before, visual information is the most important area for a driver. The majority of the new features that enrich the newest trucks are visual to a high degree, and when the connected pieces of information appear in a huge amount at the wrong time, they could easily distract the driver and become extremely mentally demanding (Schieber, 1994).

4.7 Driving Simulator

4.7.1 The driving simulator as a tool

The driving simulator is a tool to examine driving performance, in a safe and effective way. By the utilization of an experimental concept, which is repetitive and adjustable, the driving simulator makes it possible to test different driving scenarios and expose drivers in risky conditions, systematically. The driving simulator is a method which combines perceptual input, cognitive processing and behavioral output, in a reliable and valid way (Godley, Triggs, & Fildes, 2002; Hoffman & McDowd, 2010; Rosen, 2004). This tool is usually used to test specific tasks or components of the driving procedure, under specific conditions, that need to be examined (Bowers, Peli, Elgin, McGwin, & Owsley, 2005). The driving simulators are also valid for testing on road safety (Meuleners & Fraser, 2011)

The high-end simulators are expected to give results completely representative to real driving situations. Some of the parameters that could be examined are the selection of speed on a specific road, speed alterations, lane placement, reaction times, gaps to other vehicles, reactions to traffic lights and signs, overtaking decisions and time needed to feel fatigue (Bittner, Simsek, Levison, & Campbell (2002); Reimer, D'Ambrosio, Coughlin, Kafrissen, & Biederman (2006); Mullen, Charlton, & Devlin, 2011). For most cases, the validity of the driving simulators is quite enough and representative to the reality.

Meuleners & Fraser (2014) noticed that although the simulators usually provide some sound systems and dashboard displays, the vehicle does not have the actual sounds resulting from the motion and vibration a truck has. The experienced drivers usually do not pay that much attention to the instrumental display to check the performance of the truck, but they trust more the sound, the motion and the vibrations. The opposite happens to inexperienced drivers, who rely on provided systems and dashboard displays. As a result, the stimuli of the driving simulator are not that representative for experienced drivers.

4.7.2 Volvo's driving simulator

Volvo's new driving simulator (Figure 17) is an advanced fixed base simulator, including adjustment opportunities, with integrated software accompanying it. It does not have a motion base to support motions and vibrations of the cab like in a real truck, but the simulator includes several features that are presented in this chapter, which contribute in creating a realistic driving experience. The seat and the steering wheel are the two components of the new driving simulator that are almost totally adjustable. They include even more available adjustments than the actual trucks provide, enabling the driver to select his/her posture more freely.

Figure 17, Driving simulator platform

Furthermore, there are many different environments where the driver can operate, simulating different driving conditions. There is also the possibility that the driver can select the vehicle or vehicle combination he/she wants to drive including the presence or not of a trailer.

The steering wheel includes a telescopic and angular adjustment with additional neck tilt, which makes it fully adjustable (Figure 18). The adjustment is controlled by a foot pedal on the left side of the driver.

Figure 18, Steering wheel

The seat includes the armrests, seat belt and buttons that control the seat adjustment functions provided to the driver (Figure 19). Moreover, the gear lever unit is located as in reality, mounted to the side of the seat (Figure 20).

Figure 19, Seat functions - buttons

Figure 20, The seat with the gear lever unit

The accelerator and brake pedals are also functional (Figure 21).

Figure 21, Accelerator and Brake pedals

The three 75- inch monitors provide the driver with a close to reality visibility, both direct and indirect - through adjustable mirrors. Also, the instrument panel is visible in the virtual view on the monitors and there is a smaller screen behind the steering wheel, which represents the instrument cluster to display the speedometer and other vehicle information. Finally, there is a Kinect sensor (Figure 22) that adjusts the view the driver has, according to his/her head location corresponding to upper body height in the seat and additional body movements.

Figure 22, Kinect

An editor station for handling & editing product concepts and driving scenarios is found next to the driving simulator, having two computer screens and 2 keyboards, as shown in Figure 23.

Figure 23, Editor

However, the “cab” is open towards above and backwards, thus it could feel bigger and more spacious with more comfort than in a real cab. Some of the seat buttons are not the same as on the seat within the actual truck and the adjustments of the seat can only be operated manually (mechanical – not any electrically controlled seat). Regarding the steering wheel, it has an active steering motor that is however different from Volvo Dynamic Steering but gives force feedback to increase realism.

5 Case study 1: Questionnaires

The questionnaires were the first case study which was utilised at this thesis work. This chapter outlines the aim, method, results, discussion and conclusions that have arisen through this first case study.

5.1 Aim

The intention of the questionnaires was to confirm the literature findings about comfort and their relation to health problems that the truck drivers have. The focus was on realising the factors that affect the professionals' comfort inside the truck's cab.

Questionnaires were prepared and sent to Volvo drivers and employees with truck driver's license. There was also a shorter – online version uploaded in truck drivers' forums. The questionnaires that were published online aimed to confirm the findings from the long/internal questionnaires, so that it is going to be certain that the participants are not bias due to working in Volvo Group. Besides, both questionnaires aimed to develop the understanding of the different truck components, as well as an understanding of the perception of comfort, needs and preferences of the truck drivers. All the answers from both types of questionnaires were clustered in a database and enabled the better understanding and evaluation of them.

5.2 Method

A survey which is structured as a questionnaire consists of a list of questions with fixed or open-ended responses. This method is helpful in gathering information that is unique to individuals, such as attitudes, experiences or knowledge. It also allows the participation of large number of people quickly, easily and efficiently. Additionally, it is an easy way to collect and analyse data and can be conducted in different phases of the product development process. On the other hand, the use of this survey increases the difficulty to examine complex issues and to create engagements among the different respondents. Moreover, the answers that the respondents provide are usually more-limited and it is difficult for the researcher to gather more detailed information Karlsson, 2010).

In this report, a questionnaire-based survey was performed to get a deeper understanding and knowledge of drivers' typical driving postures, the factors that influence their comfort and make them to adopt new postures and the areas of their body that they experience high level of pain. The survey was both Internet based and printed and the aim was to gather both quantitative and qualitative results. It consisted of several questions with fixed answers or open-ended questions that allowed greater depth of response.

The 1st questionnaire was longer than the 2nd one and was answered by internal drivers. It included several background questions, a discomfort rating, a long truck components rating and 5 open questions (Appendix II). The 2nd questionnaire, which was online, included the same background questions, 3 multiple choice questions and 4 open questions – similar to the 1st questionnaires' questions (Appendix III).

The 1st questionnaire provided the study with many comments and helpful points of view and those comments fortunately were confirmed in a high amount from the 2nd questionnaire, also.

The outcome of both questionnaires was 44 answers and the 31 of them were in the target group of the extremes.

5.2.1 1st Questionnaire

The questionnaires that were addressed to the internal stuff were sent, through email, where the purpose of the study was explained. The internal employees and drivers were easily accessible for the group that performed the study and this enabled also the quicker receiving of results. However, the height of the participants was known only after the answer of the questionnaire, therefore the sample included answers from people that were not in the target group. Those questionnaires were quite long, including a lot of questions, so that the participants could express their point of view in a wide range of issues related to trucks.

Some general information about the questionnaires is shown in Table 2.

The answers were received from 7 women and 8 men, all having Swedish nationality. The shortest participant was 1.58 and the tallest 2.01, resulting in a wide range of heights (Appendix II). Moreover, the majority of the participants didn't have any particular physical problem and they had all driven a truck from the FH series.

Table 2, 1st Questionnaires (Long - Internal)

Starting date	End date	Total sent	Total answers	Answers in the target group	Denied to participate
6/2/15	24/2/15	48	24	15	6

Table 3, 2nd Questionnaires (Short - Online)

Starting date	End date	Total answers	Answers in the target group
6/2/15	16/2/15	20	16

5.2.2 2nd Questionnaire

A shorter version of the previous questionnaire was published online in worldwide truck driver forums and in Volvo Trucks Facebook and LinkedIn page. This version was designed in order to be quick and easy to be completed from everyone – even those who are not familiar with English- and also to collect opinions from people that are not internal employees and are maybe bias towards Volvo. Some general information about those questionnaires is presented in Table 3.

A 25% mentioned low back pain and pain in the knees and every participant was familiar with FH series.

5.3 Results

5.3.1 1st Questionnaire

The 15 participants rated the level of pain for each part of their body after having driven for a long period of time. The most common area for the truck drivers to feel pain is the lower back. On the other hand, wrists and hands are the body parts that the drivers almost do not feel pain at all.

After this, the participants had to rate the level that each of the truck components influences their driving comfort. The results represent the average rating each of the components took in a scale from 1 to 6 and the rating each component had is presented in table 3.

Table 3, Component Rating

Component	Rating
Seat	**4**/6
Steering wheel	**4,2**/6
Instrument panel viewing conditions	3,8/6
Pedals	**4,4**/6
Reach conditions	3,5/6
Visibility of surroundings	**4,1**/6
Provided space	3,9/6

In Table 3, it can be seen that the range of the rating for each of the components is not so wide. However, taking into consideration the comments the participants had and the need for narrowing down the actual problem, 4 of the factors resulted to be the most important. As a result, the pedals are a dominant factor for the perception of comfort, the steering wheel follows, then visibility of the surroundings and finally the steering wheel. Each of the components that were included in the rating, have some subcategories which were rated by the participants, resulting in a more detailed rating. In Table 4, the detailed rating of all the subcategories of the components is presented.

Table 4 shows that factors related to pedals are really important for the drivers, as well as the steering wheel adjustments. As a result, through the two types of rating, the visibility, seat, steering wheel and pedals are all highly voted to be the most important factors inside the cab that affect comfort.

Table 4, Detailed rating

Component/ Subcategories	Rating
Seat	
1.Adjustment opportunities	4,5/6
2. Backrest	4,1/6
3. Seat base cushion	4,1/6
4. Seat suspension	3,3/6
Average	**4/6**
Steering wheel	
1. Adjustment range	4,9/6
2. Gripping comfort	3,4/6
3. Steering wheel angle	3,9/6
4. Steering effort	4,5/6
Average	**4,2/6**
Instrument panel viewing conditions	
1. View of instrument cluster	4,2/6
2. View of dashboard controls	3,6/6
3. View of secondary displays	3,6/6
Average	**3,8/6**
Pedals	
1. Reach for pedals	5,1/6
2. Accelerator operation	4,6/6
3. Brake pedal operation	4,6/6
4. Foot support for left foot	4,1/6
5.Foot support for right foot	3,6/6
Average	**4,4/6**
Reach conditions	
1. Dashboard controls	3,8/6
2. Storages	3/6

3. Controls in the radio shelf	3,5/6
4. Door controls	3,5/6
Average	**3,5/6**
Visibility of surroundings	
1. Forward vision	4,3/6
2. Vision to the left	4,4/6
3. Vision to the right	4,3/6
4. Via rearview mirrors	4,2/6
5. Via close-up mirrors	3,3/6
Average	**4,1/6**
Provided space	
1. Leg room	4,1/6
2. Foot room	3,7/6
3. Knee room	4/6
Average	**3,9/6**

It was identified that the participants tended to see some of the truck components as a system. Those components were the seat, steering wheel, pedals and visibility. Through their answers in both open and close questions, they were talking about a group of components that they could not easily isolate.

Later on, when the participants answered about the part of the cab that should be improved, they mentioned that the seat is the most crucial area to be improved. Leg - knee room and steering wheel adjustments were both mentioned only by tall participants. However, better visibility of the road was a highly required improvement for short people only.

In the end of the questionnaire there was an open question about Volvo's competitors in comfort, asking the participants if they have experienced higher levels of comfort in another brand. The question was open, therefore some participants mentioned more than one brand. The most comfortable conditions in driving are provided by Scania according to the participants, then Volvo follows, DAF and finally Mercedes.

5.3.2 2nd Questionnaires

According to the participants that answered the 2nd questionnaire, the component that mostly affects the drivers' comfort is the seat. Moreover, the majority of the participants argue that drivers' reachability to the dashboard and the controls are also significant factors. The steering wheel follows in importance. Finally, the view of the instrumental panel and the pedals are less important issues for them. They also believe that the most important reasons that make them change postures are the driving situation and visibility of the surroundings. Furthermore, a dominant factor that determines their position is reachability.

Regarding the areas that should be improved, the adjustments of the seat and the steering wheel were mentioned as the most important. Some other areas that should be improved are the legroom and pedals. An interesting outcome was that both women mentioned that the seat belt is an important component that needs to be changed. It should be more comfortable and suit to their needs. Regarding Volvo's competitors in comfort, most of the drivers mentioned equally Mercedes trucks and Volvo as the most comfortable brands.

5.3.3 Common Results

Most participants of both questionnaires connected the alternation between postures to the operating environment and the type of the task. In city environment, drivers are sitting more straight, looking often around the truck - to keep track of the surroundings - and tend to have the steering wheel more horizontal. In general, they adopt a more upright posture, they are more alert and their position is connected with their need to have easier and quicker access of the controls. In highway environment, they tend to have a leaned back posture, more reclined and relaxed, having the steering wheel positioned more vertically. It is important that the driver can sit comfortably for a longer period of time. Finally, during low speed manoeuvring the drivers choose a more upright position, to be able to actively looking around and they generally do many body movements to have a better visibility.

5.4 Discussion

The questionnaires, as a method, were an effective way to gain an understanding of important aspects related to driver's comfort. The combination of open and close questions provided a variation of results, both qualitative and quantitative and enabled the participants to express themselves.

Forty four questionnaires were answered in total, with 31 being in the target group of the extremes. That amount of answers was noticeably important, as it gave the opportunity to collect point of views of a range of drivers, with different characteristics and experience. As a result, the questionnaires provided the opportunity to collect a variety of feedback. All the answers were clustered in excel files, which enabled an effective analysis and the best presentation of the results, with the use of tables and graphics.

Moreover, it was possible to investigate the different problematic situations each of the extremes of the target group face. It was possible to understand the main areas that affect driving comfort, in relation to the drivers' height limitations that this thesis has established.

It was also important, that the answers were provided from both internal and external Volvo employees. The fact that both these studies had similar results was noticeably satisfying and made the final outcomes more accurate.

Finally, almost all drivers had several comments about potential improvements, which were clustered. Based on the aforementioned comments and the quantitative results of the questionnaires, it was possible to plan the next case studies in a targeted way.

On the other side, the English language was maybe a barrier for the truck drivers, since only few people that answered through the forums had English as their native language. It could be assumed that for some participants this affected their answers, but it was tried to provide them with further explanations and communication. As a result, it is assumed that most of the participants answered in the best way possible.

Furthermore, the answers of the 1st questionnaire in the short target group were 6 women and one man, so it is not clear if the problems that are expressed in the short group are because of the height of the participants or because of the gender. Finally, in the 2nd questionnaire there were 11 answers from tall drivers and only 5 from short.

5.5 Conclusions

In city environment, the drivers adopt an upright posture, they tend to be alert and their position is connected with their need to have easier and quicker access of the controls. In highway environment, they tend to have a leaned back posture, as it is important to sit comfortably for a long period of time. Finally, during low speed manoeuvring the drivers choose a more upright position and perform many body movements to have a better visibility.

Almost all the participants agreed that the perceived comfort is mostly affected by the seat, steering wheel and vision. However, the participants that answered the 2nd questionnaire argued that reach conditions are very important, while the participants that answered the 1st questionnaire believed that the pedals are more important. As a result, there was an antithesis between the participants' point of view and a decision from the authors had to be taken about the 4th aspect that affects comfort. The final decision was that since the sample that answered about the truck components was more balanced in the long questionnaires (5 short – 5 tall) compared to the online questionnaires (11 tall – 5 short), the results could be more objective in the former. This resulted in selecting the pedals as the 4th aspect that is going to be considered, as one of the most important.

Aspects that were missing from the questionnaire according to the participants and influence comfort are first of all the climate inside the truck, including air distribution, air flow and possibilities to be alternated. This was mentioned only by female participants, as well as the lack of adjustments on the seatbelt is mainly a problem for women participants. The armrests were mentioned by both genders, as parts of the seat that have to be improved and also the buttons that exist on the sides of the seat. Those buttons are sometimes hard to be reached and also there is no way to know what they are for.

5.5.1 Tall – Short problems categorization

The most commonly mentioned comments from both questionnaires are clustered in Table 5 (more analytical in Appendix IV). The long questionnaires gave the opportunity to the participants to write more comments and express themselves, and those comments were confirmed in a high amount by the blog questionnaires also.

The amount of the total participants is 31 and 27 of them had written some comments (at least one). Seventeen of them are tall and the 10 are short. The outcome was to realize the problems the tall and short drivers have for each of the most important aspects that affect comfort, as resulted from the common conclusions. This problem – categorization was crucial for in-depth understanding of the problematic areas inside the truck's cab and for designing the upcoming studies.

Table 5, Tall - Short most common problems

	Tall	Short
Seat	○ Fit to their body dimensions ○ Wider range of length adjustments – more longitudinal adjustments available ○ Easily adjusted, without many extra movements ***"I would like just to be able to sit further back and then my knees and ankles would be wonderful, about 20-30 mm."*** ***"The seat adjustment controls have to be straightforward, so that the seat can easily be readjusted according to my current needs."***	○ Wider range of height adjustments – lower positions available ○ More free space, since they have to place the seat really forward ○ Easily adjusted – more obvious ***"Sometimes it is difficult to reach the small buttons on the sides of the seat. You don't even know which button you have to press."*** ***"Today I don't have support from the seat due to my size"***
Steering wheel	○ Fully adjustable ○ Less effort to manipulate ○ Being able to be put further back, closer to them ***"Just getting the steering wheel further back towards the driver would help me a lot, if I adjust the seat in the way I want"*** ***"It is very important that the STW can get to where I want to have it."***	○ Fully adjustable ○ Being able to reach it ○ Material and rim ***"The steering wheel should have longer adjustments"*** ***"I don't want to have the steering wheel too close to my stomach, but usually this happens. I don't have free space around me to be able to move my arms and legs"***
Pedals	○ Adjustable pedals ○ Space at the footrest ○ Support for left and right foot ***"There is too little leg room which creates problems with knee clearance. The posture gets***	○ Adjustable pedals ○ Not so high positioned from the floor level ○ More support for left foot ***"I would like a bit more space for foot support, especially for the left foot."***

	compromised." ***"I would like to have a little more upright support for the left foot. There is no support for the right foot."***	***"I would like to be closer to the pedals, but still high enough to see through the window"***
Visibility	○ Better upwards and downwards visibility ○ Bad visibility makes them sit lower ○ Obstructions from A-pillars and mirrors ***"Upwards vision is important but there are obstructions from A-pillar on driver side and mirror housings. The obstruction form external sun visor makes downwards vision tough and makes me sit lower."***	○ Not clear field of vision, if they sit as they want ○ Bad visibility though window and windscreen ○ Compromise posture always ***"If I want to have the seat lower, I won't see so well in forward vision. I want to be closer to the pedals, but still high enough to be able to see through the window."*** ***"Forward vision is affecting the seat height and usually I sit in one of the highest positions to get a good view. I always have to tilt the seat forward to reach the pedals and the floor."***

6 Case study 2: Field Tests with real truck

The field tests with real truck were the second case study which was utilised at this thesis work. This chapter outlines the aim, method, results, discussion and conclusions that have arisen through this second case study.

6.1 Aim

The field studies were originally organised by a different project, in terms of the selection of the route and the participants. This thesis work utilized the anthropometric data of the participants and the outcome of the camera recordings. Nine participants took place in these tests and the duration of each one was 70 minutes. The purpose of these studies was to have a deep understanding of how the truck drivers perform in reality, under which cases they adopt extreme postures and finally which are the most often selected postures.

Figure 24, Camera views

6.2 Method

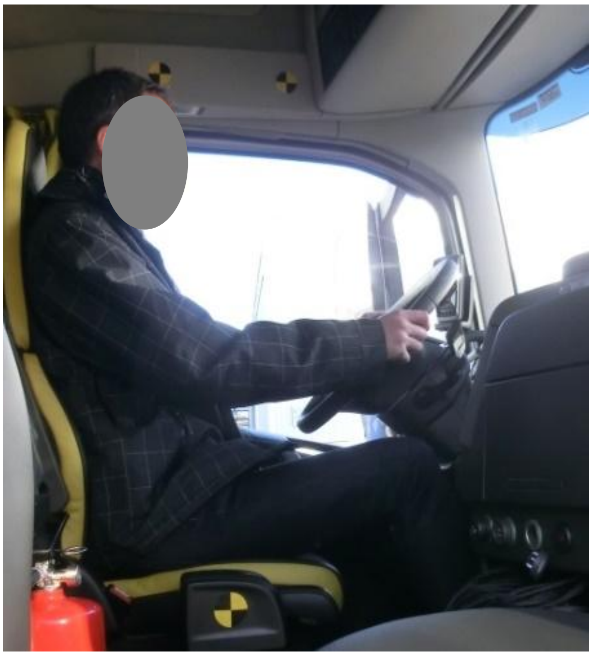
6.2.1 Preparation

I. Cameras installation

The views that were considered to be crucial for this thesis work were: the front view, view towards the road, side view and top view, therefore the 4 available cameras were positioned so as to cover these areas effectively (Figure 24). One factor that affected the positioning of the cameras was that they shouldn't disturb the driver and at the same time to provide the best-possible views.

II. Collecting seat positions

In order to collect the seat positions measuring scales, Patrick signs and an angle measurement tool were used, as shown in Figure 25. Patrick signs were placed on 2 points of the door in a distance of 30 cm between them, the gear shift and the left side of the seat. Those that were on the door and the gear shift were used as reference points, as they were visible from the side camera. The Patrick signs which were installed on the left side of the seat were used as a reference point for measuring both the height and the tilt of the seat.



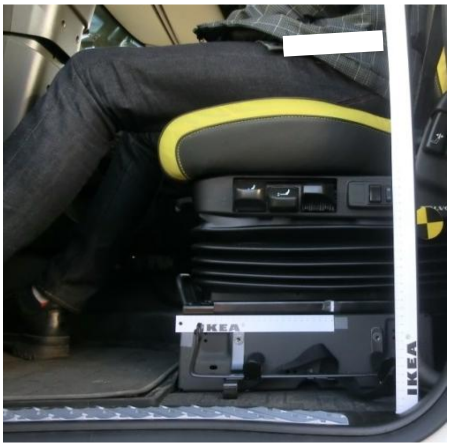


Figure 25, Collecting measurements

The digital angle measurement tool wa placed under the controls of the seat in order to measure the tilt of the seat. Also, it was located on the armrest to measure the angle of the backrest. Two measuring scales were installed vertically and horizontally, enabling the measurement of the seat length and height adjustments.

III. Collecting cameras' views from the drivers

Patrick signs were put on the shoulders of the drivers, the upper part of the arms, their right knee and right hip, as shown in Figure 26. The drivers were provided with a white, tight T-shirt so that the Patrick signs would stay on the correct position and the camera recordings would be clearer, through the contrast of the white T-shirt and the cab interior.

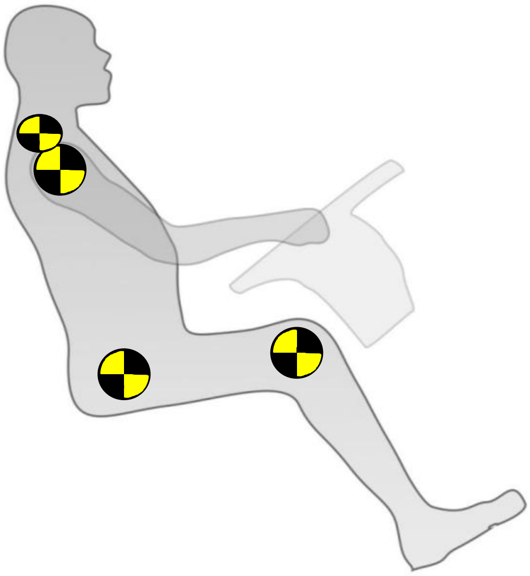


Figure 26, Patrick signs

IV. Route selection

The selection of the route was based on the idea of including city and highway driving during the 70 minutes that the tests were performed. It was important to record a variety of driving behaviours and reactions. The drivers were provided with a GPS navigator which illustrated instructions and an ordinary map showing the route they should follow. The route is illustrated in Figure 27.

Figure 27, Route map and crucial points

6.2.2 Video analysis

The videos were analysed based on two methods in order to illustrate a wide variety of different behaviours and postures while the drivers accomplished several driving situations. The first method analyses the extremes postures that the drivers adopt during each driving situation. The second method analyses the postures of the drivers in a specific driving task almost at the same moment. The aim of the utilization of both methods was to fulfill all the different aspects of identifying the postures and the factors that affect the diving postures and find new patterns.

I. Extreme postures

Purpose

The purpose of this analysis was to investigate the extreme postures that each driver adopts in specific situations. All the selected postures are in a city environment, which is more demanding. The postures are selected at almost the same part of the road or at parts with almost the same difficulty between each other, but the main focus is on the extreme moments only. Therefore, for each participant, the most extreme posture in roundabouts, right and left turns, T-junctions, intersections, merging lines and low speed manoeuvring, was chosen and analysed. The analysis focuses on the bodies of the participants independently of the cockpit.

Selection of drivers

As mentioned earlier the drivers that participated in the field tests with the trucks were chosen from another project and only 3 of them happened to be in the selected target group.

However, for the purpose of this analysis 3 more drivers were chosen, as the analysis of the previous 3 was not enough to lead to results and conclusions. Through this selection, an equivalent variety was tried to be achieved. The drivers that were selected are presented in the following table. The drivers that belong to the selected target group are in bold.

Table 6, Test drivers (the participants that have 0 years of experience, drive only few km for test purpose every year)

Test driver	Experience	Height	Gender
1	14 years	**1.70m**	**F**
2	10 years	1.74m	M
3	0 years	1.77m	M
4	0 years	1.82m	M
5	14 years	**1.86m**	**M**
6	22 years	**1.93m**	**M**

Execution

Each of the available 4 views from the camera recordings was used for a different purpose. The view towards the road was utilised so that it can be known in which part of the route the driver is performing.

The front view was utilized to identify the body inclination, which can be either towards the right or the left side of the seat. The reference line is the middle of the participant's chest. The top view was used to identify the shoulders' distance from the seat and the reference point are the Patrick signs on the shoulders, in relation to the end of the light grey upper part of the seat. The side view was used to investigate the body inclination backwards and forwards. As references, the Patrick sign on the door, in relation to the upper part of the latissimus dorsi of the driver were used. The blue line on the analyzed screenshots represents the reference line and the other color line the adopted inclination/posture.

The most demanding traffic situations and environments were analyzed for the 6 drivers and these are: 1) Roundabouts, 2) Right Turns, 3) Left Turns, 4) T-junctions, 5) Intersections, 6) Merging Lines and 7) Low speed maneuvering. The right and left turns were examined separately, to identify if there is a different driving behavior identified. Below an example of the analysis that was done follows, on the specific moments that the drivers were recorded to have their extreme postures, as shown in Figures 28-29.

Figure 28, The shortest participant performing low-speed manoeuvring – analysis example

Figure 29, The tallest participant performing low-speed manoeuvring – analysis example

Figure 29 and 30 represent an analysis example of the shortest and tallest participant, while performing low-speed manoeuvring.

The final outcome of this method was the collection of the extreme postures of all the drivers in every situation and the illustration of them simultaneously.

II. Chosen postures according to limitations inside the cab

Purpose

The purpose of this analysis is to compare the postures the drivers adopt, in a specific driving task almost at the same moment. It was tried to capture all drivers' behavior at the same time, but sometimes it was not possible since some of them behaved in a different way than the others.

Selection of drivers

For this analysis, apart from the three drivers that belong to the target group, other 2 drivers were chosen to be analysed. The reason for this decision was that the analysis of the previous 3 drives didn't lead to clear results and an equivalent variety was important to be achieved. The drivers that were selected are presented in the following table. The drivers that belong to the selected target group are in bold.

Table 7, Test drivers 2, (the participants that have 0 years of experience, drive only few km for test purpose every year)

Test driver	Experience	Height	Gender
1	14 years	**1.70m**	**F**
2	10 years	1.74m	M
3	0 years	1.82m	M
4	14 years	**1.86m**	**M**
5	22 years	**1.93m**	**M**

Execution

From the 4 available views that the camera recordings provided, the 3 were used, shown in figures 30-31. The view towards the road was utilised so that it can be known in which part of the route the driver is performing. The front view was utilized to identify steering wheel position and the position of the head and the shoulders of each participant. The reference line is the middle of the seat in relation to the Patrick signs on the shoulders.

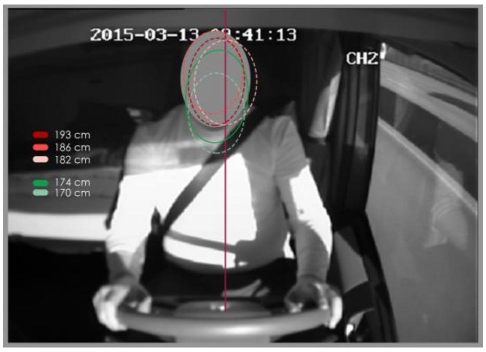


Figure 30, Position of heads - front view

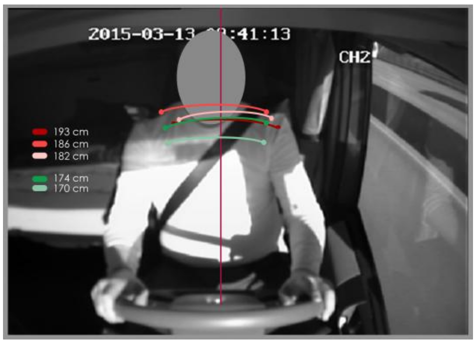


Figure 31, Position of shoulders - front view

The side view was used to investigate the seat and steering wheel inclination. As references, the grey plastic part at the backrest of the seat and the rim of the steering wheel were used. Also the side view was used to identify the position of the head, the shoulders and the knees and their height. The reference that was used in this analysis was the vertical line from the middle of the Patrick sign on the door, the armrest of the seat, the rim of the steering wheel and the Patrick sign on the shoulders and the knees. The results are shown in figures 32-34.

Figure 34, Position of backrest of the seats- side view

Figure 33, Position of heads-side view

Figure 32, Position of shoulders-side view

6.3 Results

6.3.1 Seat adjustments

Table 8, Seat adjustments

	Height	Seat length	Seat height
Test driver 1	1.70 m	5.3cm	31cm
Test driver 2	1.74 m	3.2cm	30cm
Test driver 3	1.77 m	3.5cm	30cm
Test driver 4	1.82 m	0 cm	30cm
Test driver 5	1.86 m	0 cm	31cm
Test driver 6	1.93 m	0 cm	26.5cm

All the drivers regardless their height tended to place the seat in the same height between 30 cm and 31 cm. This position is not so upwards and specifically it is in the middle of the adjustment range. However, there was a tall driver that placed the seat at 26.5 cm.

In addition, all the taller drivers adjusted their seat backwards at the 0 point and they preferred to sit more relaxed. On the other hand, the shorter sits more forwards and the shorter the participant is the more forwards he/she sits, for instance the shorter one sits 5.3 cm more forward. The above information is shown in Table 10.

6.3.2 Extreme Postures

A general outcome from the top view analysis is that the drivers tend not to adopt symmetrical postures, while driving in demanding environments and traffic situations. (Figure 35)

Figure 35, Example of non-symmetrical posture

In a more detailed analysis the following results were obtained through the first method. In merging lines(when two road lanes merge in one), almost all the drivers tend to lean slightly towards the right direction. (Figure 36)

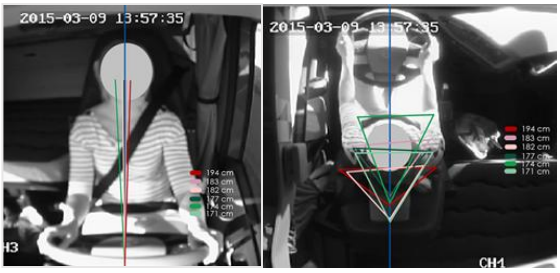


Figure 36, Example of merging lines

In roundabouts, the shorter the participant, the more forward he/she sits. The participants' bodies tend to be inclined towards the right direction in this driving situation also. (Figure 37)

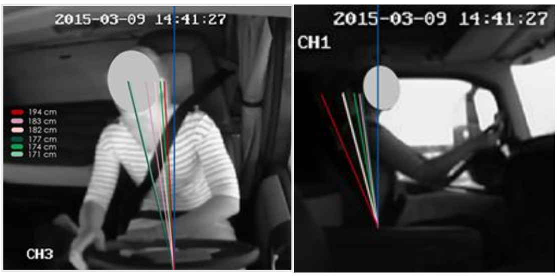


Figure 37, Example of roundabout

In right turns, the inclination of the driver's body is towards the right direction and the taller the participant, the more backwards he/she sits. (Figure 38)

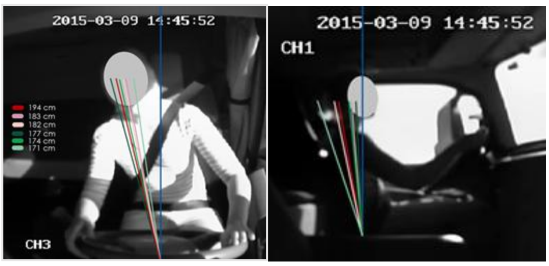


Figure 38, Example of right turn

In left turns, a quite different behaviour is identified. Four out of six participants are included towards the left direction in those turns, however they adopt less extreme inclinations. Two of them have almost no inclination and they just sit in the middle of the seat. Similarly, the taller the participant, the more backwards he/she sits, as in the right turns. (Figure 39)

Figure 39, Example of left turn

In T-junctions, the drivers behave according to the direction of the turn. Before they perform the T-junction situation, they lean forward and mostly this behaviour is identified from the shorter drivers. (Figure 40)

Figure 40, Example of T-junctions

Intersections are the most demanding situations for all the drivers. The taller the participant, the more forward he/she leans and some drivers lean towards the right direction. The tallest participant adopts the most right posture, while the shortest the most towards the centre position. (Figure 41)

Figure 41, Example of intersection

Finally, in low-speed manoeuvring, the taller the driver, the more towards the centre is inclined, but always remains in the right direction. Everyone sits in a backward position, but the shorter the participant, the more backwards he/she sits and this is the only situation where the shorter people sit more backwards than the taller. (Figure 42)

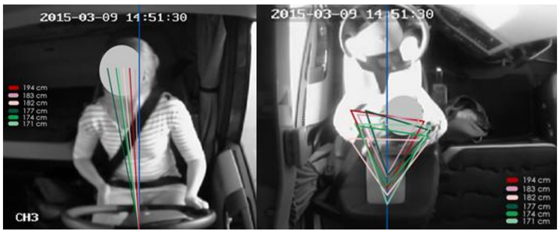


Figure 42, Low-speed manoeuvring

6.3.3 Chosen postures according to limitations inside the cab

During the entire study, the position of the seat of the shorter drivers is forward and close to the steering wheel. The seat is also placed in a high position. Additionally, the steering wheel is placed close to the dashboard and in a lower position. The area that the heads of the shorter drivers are illustrated is close to the steering wheel and downwards. Moreover, their shoulders are much lower than the shoulders of the tall. The illustration of their shoulders shows that they are moving a lot to the sides and lean forwards and there is always distance between the backrest and them.

On the contrary, the position of the seat of the taller drivers is backward, at zero point. The inclination of the backrest is higher compare to the short drivers and sometimes there is contact between the seat and the back of the driver. The seat is placed to a lower position. The steering wheel is placed close to their torso and higher compared to the shorter drivers. The taller drivers' heads are illustrated close to the backrest and upwards. Furthermore, their shoulders are close to the backrest (sometimes almost in touch). They are more stable and they move more their arms or their shoulders and less their torso and some of them lean to the left.

For each driving situation the drivers behave in different ways. For instance during the roundabouts, the drivers stay stable on the seat and just move their head towards the left direction. However, the shorter drivers (before they get in the roundabout area) tend to lean their torso forward and then to the right direction and goes back in the centre of the seat. The taller drivers either stay stable in the middle of the seat or lean to the left. (Figure 43)

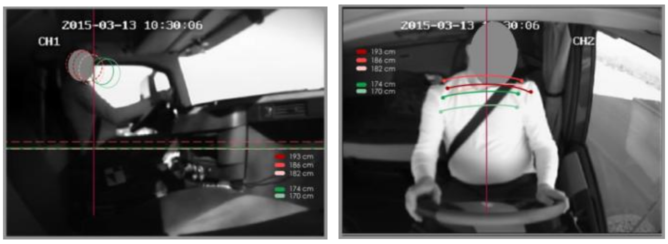


Figure 43, Roundabout

Before the drivers perform the T-junction task, they lean forward and especially the shorter ones. When they have to turn left at the T-junction their behaviour varies. The majority of the drivers lean to the left or stay stable in the middle of the seat, however there are few that lean to the opposite direction as they would have done with the right turn. (Figure 44)

Figure 44, T-junction

During the left turns, the drivers behave as they do at the T-junction. In general, they stay stable on the seat and some of them lean to the left. However, the degree of inclination is low and cannot be compared with the right turns. Additionally, there are some drivers who tend to lean to the opposite direction (right).(Figure 45)

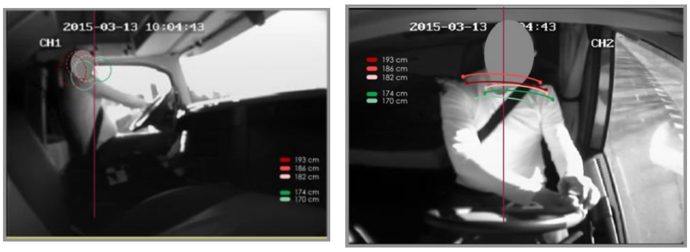


Figure 45, Left Turn

While the drivers performing right turns, they lean clearly to the right direction. However the taller drivers don't move that much and they are stable on the seat and just moves their heads and arms. (Figure 46)

Figure 46, Right turn

During driving in high way, the heads of the shorter drivers are not in touch with the seat. Furthermore, they still lean a bit forward and the position of their shoulders is more in front. On the other hand, the taller drivers seem more relaxed and their torso is often in contact with the backrest. Some of the short drivers tend to lean a bit to the right direction and they don't stay stable in the middle of the seat. However the taller drivers either stay stable in the middle of the seat or lean to the left. (Figure 47)

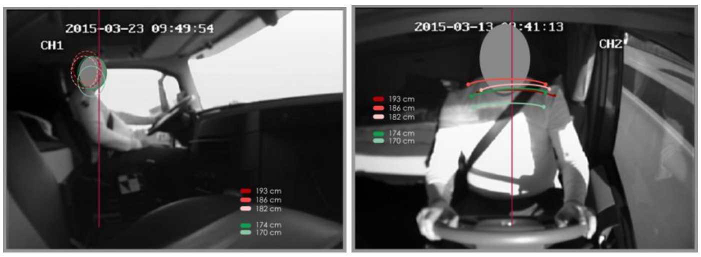


Figure 47, Highway environment

On the contrary, the heads of the shorter drivers in the city are more in front. For the taller drivers the position of the heads doesn't change so much. Their shoulders also remain almost at the same position but the position of the shoulders of the shorter ones is always more in front. It seems that the shorter drivers change a bit their posture in the city and they lean more to the right direction but the taller remain either stable or lean to the left. (Figure 48)

Figure 48, City environment

6.4 Discussion

The methods that were utilized to analyse the videos from the camera views were effective and efficient for understanding the driver's behaviour. Analysis camera views can be time consuming and to no avail sometimes at this thesis work. However, the methods that were created and utilised for analysing the videos from the camera views, were effective for understanding the driver's behaviour. The 4 cameras provided useful views inside and outside the truck. It was crucial to be able to know the exact part of the road that the driver was performing, as well as the other 3 views that were focusing on the driver's body. The cameras provided quite good videos, with a proper analysis.

The Patrick signs installation was crucial for being able to have reference points in the truck and on the drivers' body. Their placement gave many analysis opportunities. About the selection of the route, it was a highway and city route including both demanding and easy parts, which enabled a nice variation. In some areas there was traffic and the drivers had to be really careful, in others there were no vehicles and in others there were several pedestrians.

The methods that were used to analyse the videos provided a holistic image of how the drivers react in specific driving situations and gave feedback about their driving behaviour. It was also possible to identify different patterns in their behaviour and understand how the height can influence their posture while they drive. With both those methods accurate results could be achieved, both qualitative and quantitative.

However, the shoulders' Patrick signs are not always visible from the top camera and in some cases it could be difficult to have exact results about those. This happens mostly due to the seatbelt or due to the sun than affects the contrast of the area. Some drivers were confused and they chose different routes, than the proposed, although this was in limited periods of the route. Finally, there were not many people in the target group, which was overpassed by comparing the people from the target group to average height people that performed this study.

6.5 Conclusions

The city environment was the most demanding and is where drivers adopt the most extreme postures. They have to be careful about the traffic, the signs and in general to be more alert than in highway. This was obvious in the analysis of the videos. Furthermore, the seatbelt is annoying for short participants and for people with big belly. The seatbelt has a sharp vertical inclination when is adjusted for short participants and it is hurting their skin at the neck area. In participants with big belly, the seatbelt is adjusted more horizontally and less inclined, on the top of the belly, which is as well disturbing because it exerts pressure on the belly.

In general, the degree of inclination of the drivers' body during the left turns seems lower compared to the right turns.

Moreover, there is a difference between right and left turn. In general, the degree of inclination of the drivers' body during the left turns seems lower compared to the right turns. Additionally, it was identified that most of the drivers tend to sit towards the right direction. The reason for the above is visibility. The visibility on the right side of the truck is apparently limited and this is the reason why the drivers prefer to lean towards the right direction, regardless the situation or the turn's inclination. Due to visibility issues, the short participants sit more forward that the tall, so that they are able to be aware of the traffic situation in a reliable way. The most difficult part of the road was found to be the intersection, due to the demand of the best visibility in all the different road directions involved.

7 Case study 3: Driving simulator studies

The driving simulator studies were the third case study which was utilised at this thesis work. This chapter outlines the aim, method, results, discussion and conclusions that have arisen through this third and final case study.

7.1 Aim

The aim of the simulator studies was to examine and compare drivers' behaviour under driving situations, driving scenarios and several seat adjustment ranges that could not be examined in reality. The driving simulator was chosen as it facilitates the process of creating a wider range of adjustments for the different cab components, which is not feasible in real trucks. Additionally, by utilizing the tool, it was possible to examine different parameters that resulted from the questionnaires and were not possible to observe in actual trucks. At the same time it was interesting to investigate and compare if the drivers adopt the same postures in reality and in the driving simulator studies. In this study, the participants were invited to drive the driving simulator both with the current adjustments of the Volvo FH model which was used in the field tests and with a wider range of adjustments that do not exist in reality.

7.2 Method

7.2.1 Preparation

I. Camera installations

The available cameras were installed to provide the following views: front view, side view, view towards the steering wheel mapping window and view towards the measurement scales as it is shown in figures 49-50.

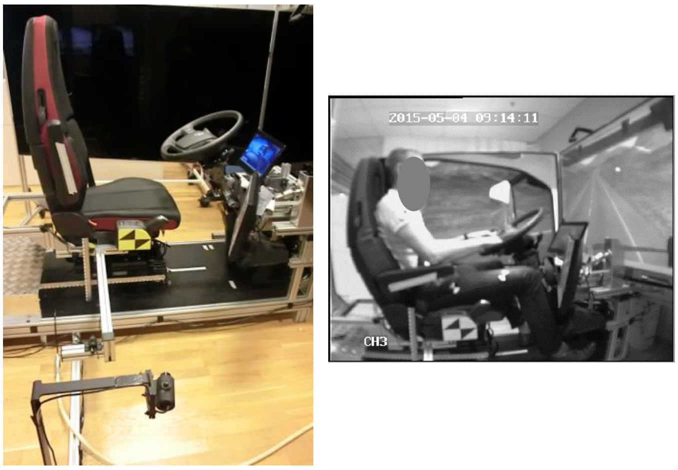


Figure 49, Side view camera

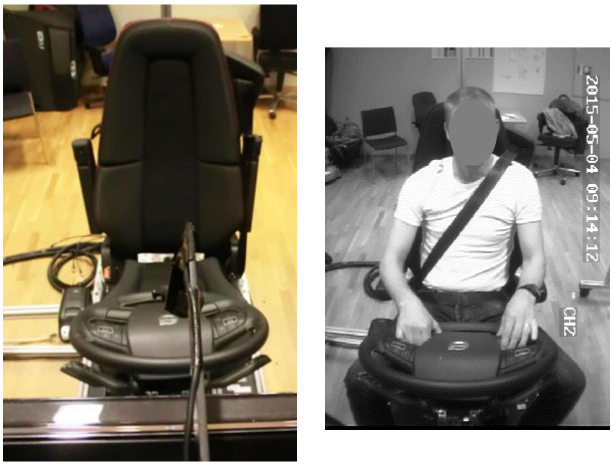


Figure 50, Front view camera

The two cameras showing the steering wheel mapping window and the measurement rulers were important because they enabled an efficient video analysis, since even the minor adjustments were recorded.(Figures 51-52) Also, it was important not to disturb the drivers by checking the adjustments while they were driving. Therefore, the cameras provided continuous measurements without the human intervention.

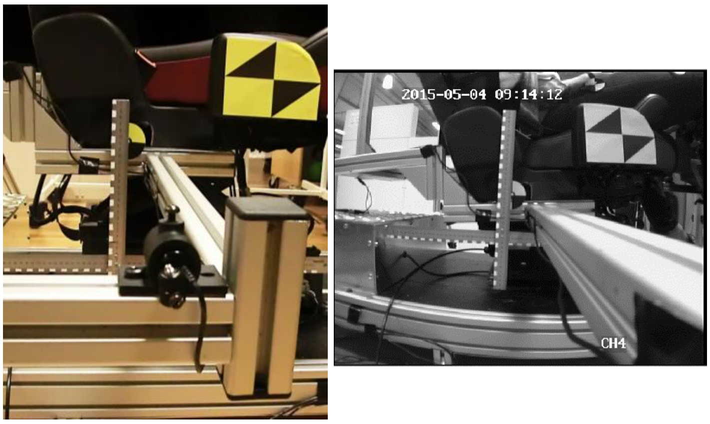


Figure 51, Close side view camera

Figure 52, View towards the steering wheel mapping window

It was important that the cameras would be corresponding to the camera orientations in the real truck, to enable a comparison between the studies in the truck and in the driving simulator. The side view provides a good view of the road, so the view towards the road, like in the real truck, was not necessary. The top view was dismissed, since there was a need to prioritize the other views with the limited number of cameras that could be handled. It was crucial that all the installations would not disturb the drivers and at the same time that they were efficient for analysing the video recordings. One test drive was performed successfully, where the 4 views were recorded, in order to test the validity of the installation and to ensure that the camera installations were properly made.

II. Collecting seat positions

Patrick signs were placed on the gear box and on the right side of the seat, as in the truck study, shown in figure 53. The Patrick sign that was placed on the right side of the seat was installed on a metal axis corresponding to the pivot point around which the entire seat can be tilted. There was no door in the simulator, so the other two Patrick signs that were used in the truck were not installed in the simulator. The mentioned Patrick sign was used as a reference point for measuring both the height and the tilt of the seat.

A metal ruler was placed horizontally under the suspension of the seat, mounted on a metal bracket to measure the seat length adjustments. It was stable on this bracket and did not move when the seat moves.

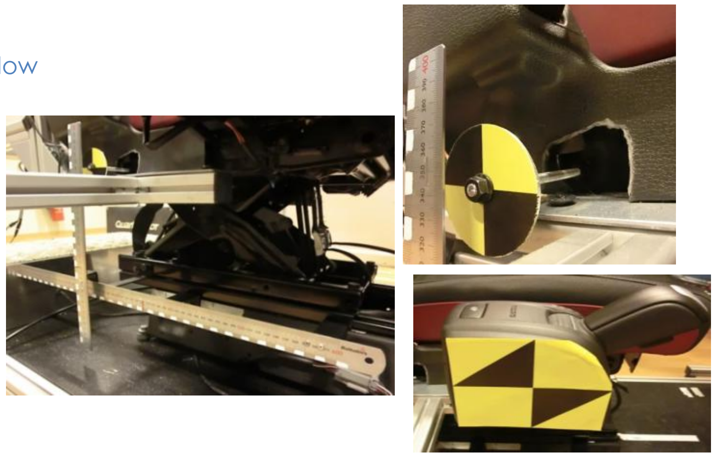


Figure 53, Collecting seat adjustments

The adjustment range for the Volvo FH model was determined and the length position of the seat was between 28 cm and 48 cm read on the ruler scale. In order to correlate the measurements of this study with the measurement of the real study with the truck the 28cm defined as the 0 point. A second metal ruler had vertical orientation and was mounted on the horizontal metal ruler under the seat suspension. This ruler was moving together with the seat and from being fixed under the seat suspension, the vertical position of the seat could be read based on where the Patrick sign coinciding with the seat tilt pivot point got located along the vertical ruler. The adjustment for the height of the seat for FH model was between 17 cm and 27 cm read on the vertical ruler. For the purpose of the project, it was essential to correlate the scale of the height of this study to the study with the real truck. In detail the 17cm of the scale corresponded to 26.5cm and the 27cm to 36.5cm of the scale of the study with the real truck. The metal rulers were painted white every second cm to support more distinct reading in the subsequent video analysis.

III. Collecting camera views of the drivers

Patrick signs were put on top of the right shoulder of the drivers, the upper part of the arms, their right knee and right hip (Figure 54). The drivers were provided with

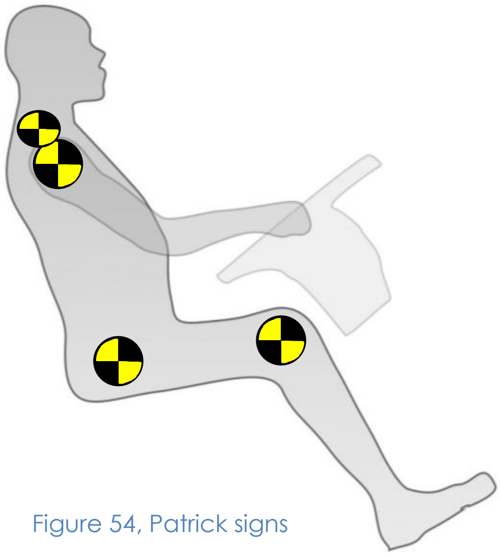


Figure 54, Patrick signs

a white, tight T-shirt so that the Patrick signs would stay on the correct position and the camera recordings would be clearer, through the contrast of the white shirt and the cab environment. The Patrick signs were placed in the same place as in the previous real truck tests, so that a comparison could be possible.

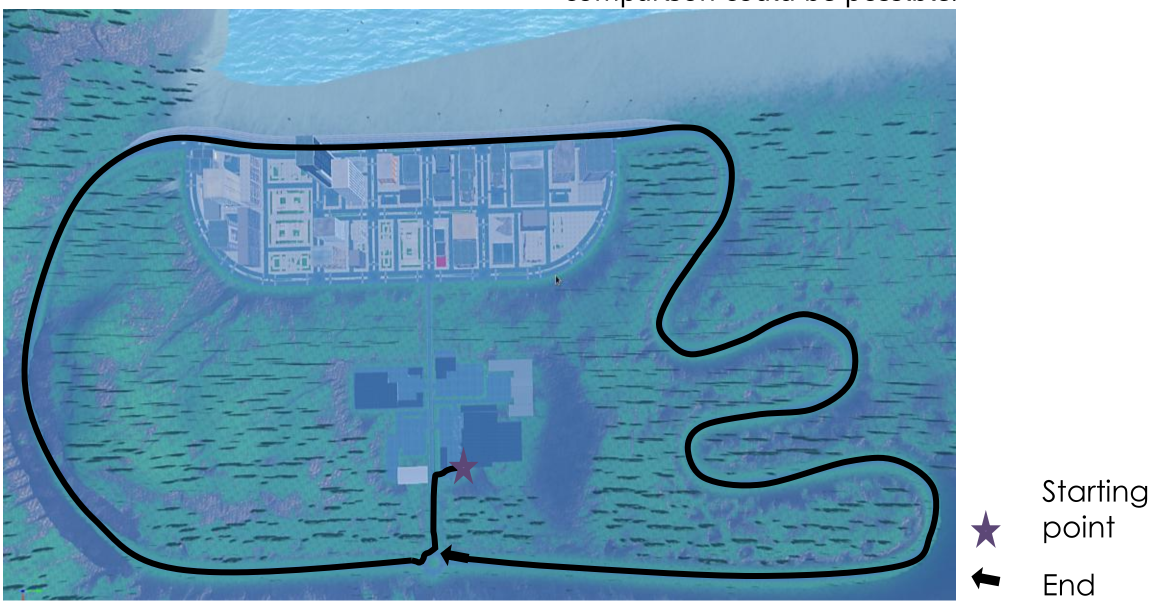


Figure 55, First Round

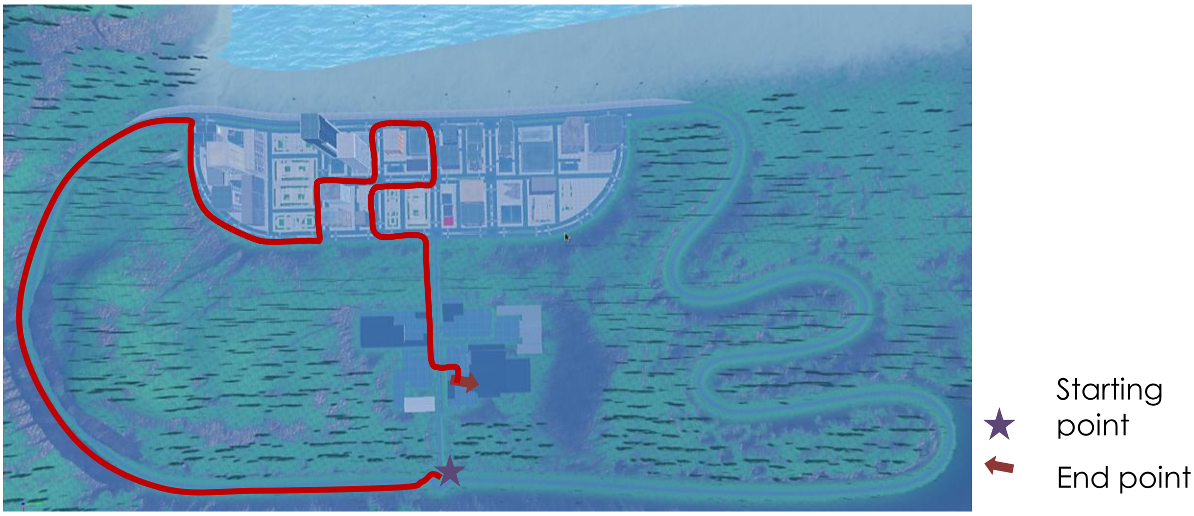


Figure 56, Second Round

IV. Route selection

The available scenario was a Brazilian road environment, which included city driving, highway driving and a parking area for performing low-speed manoeuvring. The whole scenario was over in a fairly short time period. Thus a decision was taken to make some iterations for each session.

Two iterations were decided to be performed. The selected iterations included city environment, highway, parking area, roundabouts, sharp turns, intersections and T-junctions. The first iteration, shown in Figure 55, was designed to be simpler than the second one, where the drivers performed more city driving. This was planned so that the drivers would have the time to get used to the simulator before they had to perform the more demanding tasks. The second iteration is represented in Figure 56. In general, the intention was that the test drivers would drive almost in the same environments and driving situations as they drove with the truck for the field tests. In this way some conclusions and common results could be obtained.

V. How participants were chosen

The drivers that participated in the driving simulator studies were some of the drivers that answered the questionnaires in the beginning of the thesis. Three of the people that answered the questionnaires, participated also in the truck field tests and they were also invited to participate in the simulator tests. In total there were 7 drivers who accepted to participate, whose heights are shown in Table 9. As in the previous two studies, in this one also, it was essential to involve a range of driver statures. The shortest participant was 1.58 m as in the questionnaires and the tallest was 1.94 m. This contributed to have a variety of results corresponding to the target group of the Thesis project.

Table 09, Participants

Test driver	Years experience	Height	Gender
1	14	1.86m	Male
2	5	1.89m	Male
3	10	1.58m	Female
4	29	1.94m	Male
5	14	1.70m	Female
6	22	1.93m	Male

7	5	1.61m	Female

VI. Start-up procedure

The startup procedure of the simulator was on the one hand complicated, but on the other hand necessary, in order to provide the drivers with a customized driving experience. In order to calibrate the simulator according to the actual eye point of each participant, it was necessary to make a measurement of the seat height offset and the seat length offset, using the installed rulers. Negative sign was added on the offset if the seat was adjusted downwards/backwards and positive sign if the seat was adjusted upwards/forwards.

The mirrors were also adjusted according to the preferences of each test person. This was done via the simulator keyboard by one of the authors. The aforementioned calculations took 4 minutes which could in parallel be used to collect interview answers from the test participants.

7.2.2 The procedure

The studies were performed between the 29th of April and 6th of May in the driving simulator laboratory and covered 7 participants who were Volvo drivers and employees with truck driver license. They also had a varying degree of driving experience and had driven from 1000 to 10000 km annually. The order of the studies was made according to the participants' stature although the procedure and the content maintained the same in order to achieve accurate and representative results.

Each study included background questions, measurements, two main sessions and general questions. The participants received the same basic information about the different components and features within the driving simulator, as well as the traffic safety rules they should follow.

Two separate sessions were held to validate the factors that cause transition between several postures and indicate which postures contributed most to drivers' comfort. The drivers followed a specific route and they started driving from the countryside to the city and then back to the countryside for 15 minutes. During driving, they also performed a parking maneuver and there was a suggestion of adjusting the seat position according to every new driving condition.

During the 1st session the drivers were provided with the possibility to adjust the components according to the current Volvo FH adjustment ranges. Therefore, they were experiencing the driving task as in ordinary trucks. After the first session, a semi-structured interview was held. It consisted of several questions about each driver's experience during driving. Then, the drivers followed the same procedure for the 2nd driving session but the cockpit allowed them to have more "free" positions for the seat. In detail, they were provided with wider range of adjustments for the length and the height of the seat. A second semi-structured interview was carried out at the end of the 2nd session and the main purpose was to compare drivers' comfort with the previous session. Finally, a third interview was conducted and focused on issues related to drivers' experience with the different cockpit components and the driving simulator.

7.2.3 Observations

Observations were also used in the studies by utilising the driving simulator. They occurred in a laboratory environment in order to perform several tasks that cannot be accomplished in real trucks. The observations were combined with interviews, according to Jordan's (1998) recommendations, to enrich and confirm the information from the users' perspective. They were documented with photographs, voice and video recordings in order to increase the accuracy of the results.

The objective of the observations was to provide insights about the behaviour of the participants while performing different driving tasks. It was essential for the studies to observe the changes of the adjustments of the different cockpit components without disturbing the participants.

7.2.4 Interviews

I. Purpose

Interviews are the predominant method for gathering accurate information about users' thoughts, experience, emotions, and attitudes. While performing interviews there are several aspects that should be considered. For instance, the number of interviewees that is necessary to identify the needs of the average user. Another aspect is the criteria that should be used in order to choose the most suitable participants to achieve a valid result.

Interviews can be categorized into structured, unstructured or semi-structured (Bohgard, M. et. al, 2009).

In this study the interviews were semi-structured in order to gather both quantitative and qualitative results. During the semi-structured interviews, the questions were prepared but used as a basis for discussion. Therefore the context of the interview was more relaxing and the users could explain their opinion in more depth. Pre-defined questions were used for each session and everything was documented with voice recordings and written notes.

II. Execution

Interviews were conducted at the end of each driving session and the aim was to confirm the selected data results from the previous questionnaires and especially identify the main truck components that should be improved.

The three interviews examined different aspects and each one contributed to an in-depth understanding of drivers' behaviour. For instance, the first interview comprised questions which were associated with the controls of the seat and the steering wheel, the adjustability of the different cockpit components, the perceived comfort and the comparison between the postures adapted in reality and in the simulator. The second interview focused on the perceived comfort after the freely adjustment of the components. The final interview consisted of questions that examined several parameters like visibility, reachability of pedals and the adjustments of the seat and the steering wheel. Each interview was documented with voice recording and written notes. In addition to this, the 2nd and 3rd interview requested the participants to provide a rating against a 6-level scale with figures of various facial expressions corresponding to their level of comfort in the different driving situations (Osvalder , Hansson, Stockman, Carlsson , Bohman , & Jakobsson , 2013).

As mentioned earlier, there was one participant that quit the driving exercise, but he was able to answer all the interview questions. As a result, the interview answers were taken from 7 drivers.

7.2.5 Video analysis

I. Seat adjustments comparison between 1st & 2nd sessions

Purpose

The purpose of the seat adjustments comparison was to investigate the seat adjustments the drivers select when they have limited adjustment opportunities, in comparison to when they have free adjustment opportunities. Furthermore it was possible to perform a comparison of the short and tall drivers' behaviour.

Execution

In the beginning of each driving session the seat was placed in an awkward position so that the drivers would be obliged to adjust it in order to be able to sit and drive, as presented in Figures 58 and 59. The camera recordings provided the seat adjustments the drivers did in the beginning of the each session. The installed rulers were used for the calculations.

Figure 58, Seat awkward position before each session

Figure 59, Steering wheel awkward position before each session

II. Steering wheel adjustments

Purpose

The aim of this investigation was to identify which was the range that the steering wheel adjustment range was used by the different people of the target group. Moreover, it was crucial to understand if there was a relation with the chosen seat positions or if they were independent. The frequency that the drivers changed the steering wheel adjustments was also of great importance.

Execution

In the beginning of each driving session the steering wheel was placed in an awkward position so that the drivers would be obliged to adjust it in order to be able to drive. The camera recordings provided the steering wheel position within the available steering wheel mapping window that the drivers chose in the beginning of the each session. CAD models were used to compare which position within the mapping window corresponded to the actual selected position of the steering wheel.

III. Chosen postures according to limitations inside the cab

Purpose

The aim of this analysis was to compare the postures the 7 drivers adopt, in four specific driving tasks that took place almost at the same moment within their respective sessions. It was decided to capture all drivers' behavior at the same time during the second session of the studies because then the drivers were more familiar with the procedure and they were driving in a manner more close to reality.

Execution

For the analysis, the two camera views were utilized. The front view was used to identify steering wheel position and the position of the head and the shoulders of each participant. The reference line was the metal tube that supports the overhead Kinect sensor (behind the seat) in relation to the Patrick signs on top of the shoulders. (Figures 60-61)

The side view was utilized to investigate the seat and steering wheel inclination as well as the position of the head and the shoulders.(Figure 62-63)

Figure 53, Position of heads-front view

Figure 61, Position of shoulders-front view

Figure 62, Position of shoulders-side view

Figure 63, Position of heads-side view

7.3 Results

7.3.1 Seat adjustments comparison between 1st & 2nd session

The tall drivers adjusted their seat from 0 to 1 cm more upwards and from 3 to 8 cm more backwards in the second session. From the documentation represented in Table 10, it is shown that they utilized the extra length adjustment provided. They preferred to sit relaxed and backwards. In detail some of the drivers chose to sit 8 cm more to the back compared to the adjustments of the Volvo FH model.

Moreover, it is shown that during the first session they sat at the zero point as they did in the real truck and also the chosen height of the seat had the same results as in the real truck. In detail their choice was in the middle of the adjustment scale of the Volvo FH model apart from the tallest driver.

Table 10, Drivers' characteristics

Test driver	Height	Knee Height	1st session	2nd session	1st session	2nd session	Results - Comparison
			Height	Height	Length	Length	
1	1.86 m	65 cm	31.5cm	34.5cm	0cm	-3cm	Does not count
2	1.89 m	70 cm	30.5cm	31cm	3.5cm	-2cm	0.5 cm more upwards and 5.5 cm more backwards. He utilized the extra space back.
4	1.94 m	73 cm	26.5cm	26.5cm	0cm	-8cm	The same height of the seat and 8 cm more backwards. He utilized the extra space back.
6	1.93 m	73 cm	30.5cm	31.5cm	0cm	-3cm	1 cm more upwards and 3 cm more backwards. He utilized the extra space back.
3	1.58 m	50 cm	30.5cm	32.5cm	13.5cm	15.5cm	Upwards 2 cm and forward 2 cm. She didn't utilize the extra adjustments.
5	1.70 m	62 cm	36.5 cm	38cm	7.5cm	7.5cm	Upwards 1.5 cm and stayed in the same length adjustment. She utilized the extra adjustments.
7	1.61 m	47 cm	27cm	27.5cm	35.1cm	36cm	Upwards 0.5 cm and forward 0.9 cm. She didn't utilize the extra adjustments.

On the other hand, the short drivers adjusted their seat from 0.5 to 2 cm more upwards and from 0 to 2 cm more forwards. They did not utilize the extra length adjustment, however they preferred to sit close to the steering wheel and forwards. As shown, some of the short drivers changed their position during the second session but the new length positions were still in the range of the adjustments in the existing Volvo FH model. Additionally, the length preferences during the first session seem to be similar with those at the real truck since they sat even 13.5 cm forward but the height of the seat is not the same. In particular some of the short drivers sat higher. Moreover, there was one short driver that utilize the high adjustment and sat 1.5 cm more upwards.

In addition to this, almost all the positions of the drivers are correlated with the height of their knees. The drivers with lower knee locations were closer to the dashboard and the drivers with higher knee locations were more backwards. In detail, the tallest driver had knee height 73 cm and he placed the seat 8 cm more backwards than the maximum adjustments of the FH model. Moreover, the shortest driver had knee height 50 cm and she was very close to the steering wheel. On the other hand, the shortest driver who was 1.58 m tall and had knee height 50 cm was much closer to the dashboard than a short driver who was 1.61 m tall and had a knee height of 47 cm.

Furthermore, the tallest driver who was 1.94 m tall had the same knee height with another tall driver who was 1.93 m tall, however the tallest chose to sit 8 cm more backwards and the other one only 3 cm backwards.

7.3.2 Steering Wheel Adjustments

The possibilities of adjustments that the steering wheel enabled in the simulator are represented in Figure 64.

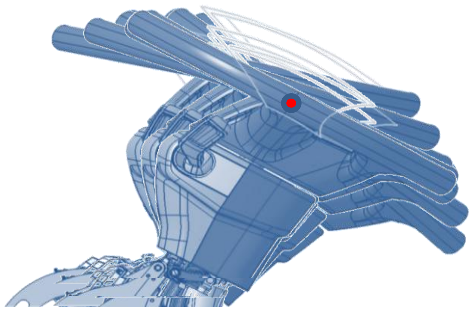


Figure 64, Steering wheel adjustment range

The installation can be seen in Figure 65, where with the help of the yellow plastic frame (mapping window) the selected position could be translated to a specific position of the steering wheel.

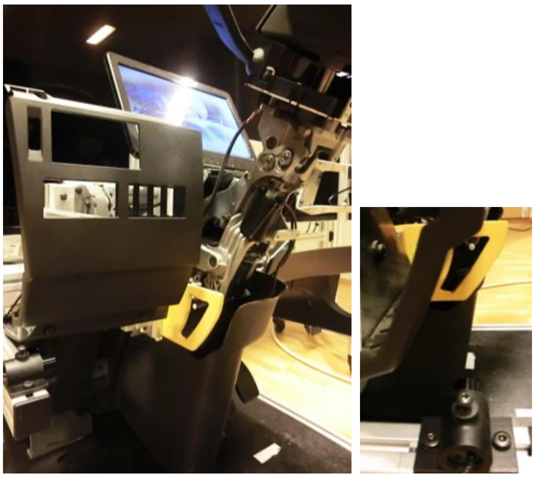


Figure 65, Mapping Window

The results in the steering wheel adjustments are quite similar with the results from the trucks. The short participants adjusted the steering wheel close to the dashboard and in a lower position. The tall participants adjusted the steering wheel close to their torso and sometimes higher compared to the shorter drivers. As can be seen from Table 11, during the first session the adjustments varied much more than in the second session. Especially the tall drivers readjusted the steering wheel many times.

Table 11, Adjustments that were done in each session

	Arm length gripping	Experience In years	Gender
1st driver - 1,86 m	68 cm	14 years	M
2nd driver - 1,89 m	67 cm	5 years	M
3rd driver - 1,58 m	56 cm	10 years	F
4th driver - 1,94 m	70 cm	29 years	M
5th driver - 1,70 m	59 cm	14 years	F
6th driver - 1,93 m	72 cm	22 years	M
7th driver - 1,61 m	55 cm	5 years	F

There is a common behaviour between the participants that have almost the same height: 1.93 & 1.94 and 158 & 1.61 m. They also have very similar arm length gripping measurements (Table 11). Both tall and short participants select a position pretty close to the Neutral position of all the steering wheel positions provided, which cannot be explained.

From Figures 66,67 it can be seen that the short participants have more concentrated preferences , than the tall drivers who don't have clear preferences.

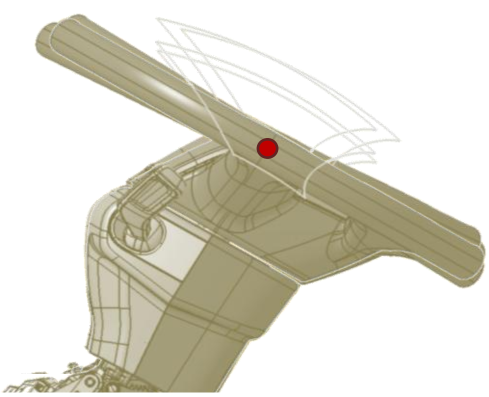


Figure 66, Short participants' adjustments

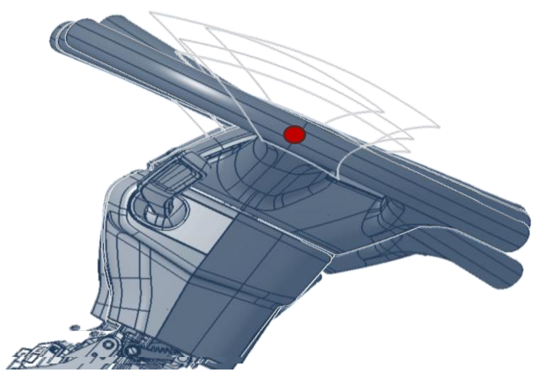


Figure 67, Tall participants' adjustments

In the 1st session the tall participants adjust more times the steering wheel, in order to find the position that suits them best. However, it is interesting that for the majority of the participants, the adjustment of the steering wheel they selected in the 2nd session was also one of the selections they had in the 1st session. It was noticed that every adjustment of the steering wheel was done during driving in the highway environment. When driving in the city, the participants were concentrated on the task and they did not do any adjustments.

7.3.3 Chosen postures according to limitations inside the cab

During the study, the position of the seat of the sorter drivers is forwards but the degree of inclination of the backrest is not as much as it was at the studies with the real truck. Moreover, the seat is placed higher and the steering wheel is placed close to the dashboard and in a lower position. The area for the heads of the shorter drivers is close to the steering wheel and downward. Furthermore, their heads are not in touch with the seat but they are closer to it compared to the study with the real truck. Moreover, their shoulders are close to the steering wheel and much more in front than the tall drivers. There are some cases that the shorter drivers lean to the right more than the tall ones (especially at the roundabouts) and they do not stay stable in the middle of the seat.

On the contrary, the position of the seat of the taller drivers is backwards. The inclination of the backrest in some cases is much more than the inclination of the seat of the short drivers. In addition to this, the seat is placed to a lower position. The steering wheel is placed close to their torso and higher compare to the shorter drivers. The taller drivers' heads are in general close to the backrest and higher, but there are some drivers who are sitting a lot downwards. Moreover, their shoulders are close to the backrest compared to the short drivers. They stay more in the middle of the seat and they lean to the sides during the turns.

In general during the different driving tasks the drivers behave in different ways depending on their height. For instance during the roundabouts, the tall drivers stay more stable on the seat. Even the shorter drivers tend to be calm and do not move their torso forwards that much. However, they lean more to the right compared to the tall drivers, and they are also turning their heads depending on the direction of the road.(Figure 68)

Figure 68, Roundabout

Before the drivers perform the T-junction task, they lean a bit forward and especially the shorter ones. Some of the drivers lean to the left but, as mentioned also for the studies with the real truck, there are several drivers that lean to the opposite side. (Figure 69)

Figure 69, T-junction

While the drivers performing right turns, they lean to the right direction. All the drivers move to the right and they do not stay stable in the middle of the seat. (Figure 70)

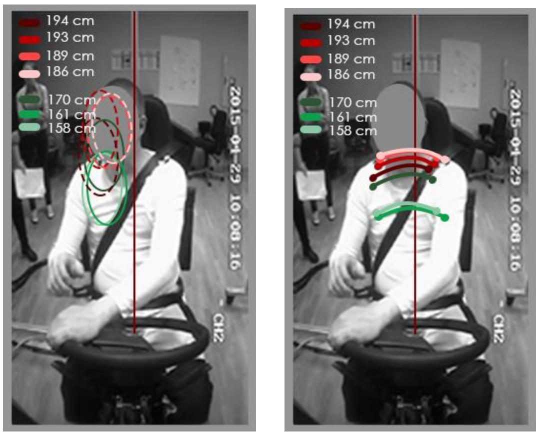


Figure 70, Right turns

During the left turns, the drivers behave similar with the T-junction and they do not lean to the left. However, the degree of inclination is low and cannot be compared with the right turns. (Figure 71)

Figure71, Left turn

In general, the degree of inclination of the drivers for every situation within the driving simulator study is lower than the chosen inclination within the studies with the real truck.

7.3.4 Interviews

I. Questions

The participants answered the question about if they adopted the same postures as in reality and everyone spontaneously answered that the postures they adopted were quite close to reality. However, when they explained their answer more and they thought more about it, everyone agreed that there were some factors that could have affected their driving behaviour and in reality they would maybe have driven quite differently (Table 12).

Table 12, Factors that affected the chosen posture in the simulator

1st factor (6 out of 6 participants)	**2nd factor (6 out of 6 participants)**
The short period of the test.	**The lack of other vehicles and pedestrians in the used driving scenarios.**
"If I drove more, probably I would have changed my postures more"	*"Maybe I adopted more neutral postures, as I didn't have to take care of other cars or people"*

Furthermore, there was a question about the driver's ability to adjust the cockpit components they want during driving. The purpose of this question was to understand if the drivers would have liked to adjust the components within the cab even if they could not, or if they just prefer to move their body instead of adjusting the components within the cab when the driving situation demands it. This was a question that arose after the video analysis, where it was obvious that most of the drivers prefer to adopt awkward postures instead of re-adjusting the steering wheel or the seat, so that they follow their body which results in non-ergonomic postures. The answer was quite interesting, as seen in Table 13.

Table 13, Answers about adjusting components while driving

Experienced participants	**Inexperienced participants**
They adjust everything they want during driving and they do not face any difficulties to do this.	**They adjust the components within the cab once in the beginning and then they continue driving with those adjustments until the next stop.**
"I adjust everything I want while driving, if I feel uncomfortably"	*"I don't feel safe adjusting the seat or the steering wheel while I drive, so I keep everything as it is "*

These answers were in contrast with reality though, since according to the videos almost no one adjusted his/her posture while driving, neither the experienced, nor the inexperienced drivers.

Moreover, there were some more questions that are presented in Table 14.

Table 14, Final answers

Participants that adjusted the seat and the steering wheel differently in the 2nd session, compared to the first.	**4/6**
Participants that noticed choosing other adjustments	***3/6***
Participants that felt more comfortable in the 2nd session	***3/6***

7.3.5 Discussion

Through the interviews that were performed, it was possible to investigate and have a deep understanding of the different problematic situations each of the extremes of the target group face. It was possible to understand the main areas that affect driving comfort in relation to the drivers' height limitations. The participants expressed themselves in a straightforward manner, said their opinions, provided their ideas and nice conversations emerged. The feedback that the interviews gave was valuable for the final results.

The methods that were utilized to analyze the videos from the camera views were effective and efficient for understanding the drivers' behavior. The 4 cameras provided good views of the driver's posture and of the seat and steering wheel adjustments. It was crucial to be able to know the exact part of the road that the driver was performing, and this was possible through the side camera. The cameras provided quite good videos, with satisfactory opportunities for analysis.

The application of Patrick signs was crucial for being able to have reference points in the driving simulator and on the drivers' body, and their placements gave many opportunities for analysis. About the selection of the route, it was a route including both demanding and easy parts, which enabled a nice variation.

The methods that were used to analyze the videos provided a both specific and holistic picture of how the drivers adjust the seat and steering wheel in relation to the driving conditions. It was also possible to identify different patterns in their behavior and understand how the height can influence their posture while they drive.

The fact that the study with the real truck had already been performed, enabled a more efficient and effective way of working with this study. The most crucial parts and the mistakes that should be avoided could already be taken into consideration. Therefore everything worked smoother and better.

However, it is not clear if the results are connected to the gender, since each of the groups of extremes is represented by one gender. It was particularly demanding to find drivers of both genders in the selected target group. Also the driving experience within the two target groups varied, with the tall drivers having more experience than the short.

Furthermore, the lack of traffic in the driving simulator scenario was important, since traffic is a crucial factor that affects the posture of the drivers. Finally, the lack of the neck-tilt at the steering wheel of the driving simulator, which was provided in the real truck and enabled more steering wheel adjustment opportunities, could have affected the results.

7.4 Conclusions

In the 2nd session of the driving simulator tests it is assumed that the drivers' behaviour is more representative to the reality. This is proven in the stability the drivers show in their preferences among the possible adjustments they do of the steering wheel and the seat. Also, it was observed that their performance was noticeably improved in the second session. Therefore, most of the results and conclusions are obtained from the analysis of the 2nd session.

In general, the tall drivers are less satisfied than the short with the adjustments that are currently provided by the cab of the truck. As a result, the tall drivers seem to compromise their posture in order to fit inside the current cab, while the short people are satisfied with the current available adjustments.

Furthermore, the analysis of the videos demonstrated that the seat and steering wheel adjustments were done in highway by the drivers, because the city environment was really demanding and they were concentrated on driving. This is in contrast with the reality, since it was identified from the second case study that the drivers prefer to adjust the cab components while they drove in the city environment.

The steering wheel adjustments selected by the tall and short drivers were more concentrated for the short drivers that for the tall. The short drivers selected the low forward position of the steering wheel bottom left area of the mapping window, which is translated to a lower and more forward adjustment of the steering wheel. The tall drivers selected adjustments that were located in the centre of a vertical axis, but the height varied. This is quite interesting as one would expect that they would have adjusted the steering wheel as high as they could and more rearwards. It is a question if the reason for this was the lack of the neck-tilt that provides a wider range of angles for the steering wheel, enabling at the same time the visibility of the speedometer.

In addition to this, during the analysis of the videos, it was noted that there was a difference between right and left turn. In general, the degree of inclination of the drivers' body during the left turns seems lower compared to the right turns. Furthermore, it was identified that some of the drivers and especially the short tend to sit constantly inclined towards the right. The reason for the above is most likely visibility. Visibility on the right side of the truck is limited and this can therefore be assumed to be the reason that the drivers lean towards the right direction, regardless of the traffic situation or the direction of the turn.

8 Cross-case Analysis

In this chapter, the three case studies are examined together, with a focus on the similarities and differences across them.

Through the three case studies that were held, it was possible to identify the needs of the truck drivers in relation to comfort.

A highlight of the first case study was that the participants were not aware of the postures they adopt while driving or about their driving behaviour and preferences, in general. They only realized that they move their body and adjust their posture when they change driving environment from city to highway and vice versa. Through the second case study, it was confirmed that the participants adjusted their posture much more than they thought. However this could not be confirmed through the simulator studies, since the inclination of the bodies was less, compared to the real truck studies. In the simulator studies every movement of the participant's body was smoother and as mentioned earlier, there were main differences in the real truck studies and the simulator studies, which may have affected this result. The main differences are presented in the table 15.

Table 15, Main differences between the real truck and the simulator studies

Close to real truck	Lacks in the simulator
Same adjustment ranges as in FH truck	No neck tilt in the steering wheel
Steering wheel	No traffic
Seat	Not the same representation of the interior parts
Kinect sensor for customization	Not the same driving scenario and time of driving

However, in the real studies and the simulator studies it was still possible to confirm some typical motion patterns according to the driving situation. Personal driving behaviours and adjustments were identified in both case studies. All the drivers had one or more favourite postures, which the roughly followed in the simulator, in a less extreme way. The driving tasks that were the most demanding for the participants were the sharp turns and the intersections and these were the tasks that the drivers changed their posture and adopted the most extreme ones. Also, the city environment was confirmed to be the most demanding one, from both the second and the third case study. (Figure 72)

Figure72, *Demanding driving tasks in reality and simulator*

However, there were some interesting observations that resulted only from the second case study, while the participants drove in an actual truck. Different behaviour was identified in right and left turns, especially in the real truck studies. The drivers tended to move a lot during the right turns, in contrast with the left turns, due to lack of visibility. In general, the short drivers leaned more forward that the tall drivers. They also needed some time to prepare themselves before the next driving task. (Figure 73).

Figure 73, *Preparation before a roundabout*

The tall participants were more relaxed and adjusted the cab components while driving. (Figure 74)

Figure 74, *Relaxed driver*

In the real truck it was identified that almost all drivers leaned to the right side of the seat, after few minutes of driving and they tended not to adopt symmetrical postures while driving. (Figure 75)

Figure 75, *Preparation before a roundabout*

In general the drivers experience the cab components as a system. The truck components that were able to be tested through all the three case studies were mainly the seat and the steering wheel. In the first case study, the tall drivers claimed that they need a longer range of seat length adjustments and this was confirmed through the second and third case study. In detail, during the ride with the real truck, the tall participants selected the most backward length adjustment opportunities and during driving the simulator they utilized the extra seat length adjustments that were provided.

They usually prefer to sit backwards in a more relaxed position and this was confirmed as well, from all the case studies.

Regarding the short drivers, in the first case study they mentioned that they need to be placed more upwards in the cab, for having better control of the surroundings. This was shown both in the truck, where the shorter drivers selected the upper adjustment seat range and in the simulator, where they used the extra height adjustments provided. The short drivers tend to drive in a more upright posture in general, as they obtain better visibility.

Concerning the steering wheel, the majority of the participants claimed that they would like to have more adjustment opportunities. The tall participants claimed that they would like to be able to bring the steering wheel more close to them, which means longer adjustment range. The short participants would prefer more available angles that the steering wheel can be adjusted, so that they can achieve a comfortable angle, mainly in upward positions. In the second and third case studies a common behaviour between the participants that have almost the same height was observed, regarding the steering wheel adjustments, confirming the results from the first case study. It was highlighted from the second and third case studies that the tall participants adjusted the steering wheel more times while they were driving. During driving the real truck, the participants adjusted the steering wheel in the city environment most of the times. This is in contrast with the simulator studies, where the participants did the adjustments on the highway.

9 Posture Results & Design Proposals

In this chapter the most common postures will be analysed, as well as several design proposals inside the cab.

9.1 Postures

Truck drivers adopt several postures while they drive. The studies with the real truck and the driving simulator demonstrated that they sit in different ways depending on the driving situation. In general, all the drivers have one or more favourite postures, which they keep for the majority of their working time. However, while they are performing difficult driving tasks like sharp turns or at the intersections they change them and they adopt more extreme postures. Furthermore, all the studies showed that the short drivers tend to lean more forward.

In addition to this, the drivers, regardless their size, have different behaviour in right and left turns. They tend to move during the right turns in contrast with the left turns, due to visibility issues. Besides, the videos from the study with the real truck illustrated that almost all drivers lean to one of the sides of the seat and they do not stay stable in the middle after a few minutes of driving. In particular the majority of them lean to the right side of the seat. However, this behaviour was not that noticeable in the studies with the driving simulator.

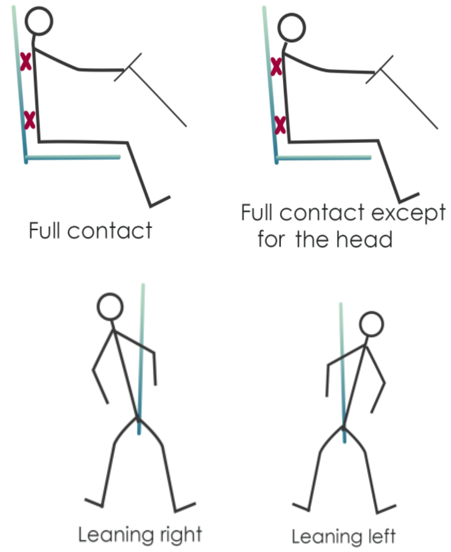


Figure 76, Driving in highway

In the highway (Figure 76), the drivers are more relaxed and they sit more backwards. They are either in touch with the backrest or they lean a bit forward. This means that they are either in full contact with the seat or they are in contact with the seat except from their heads. Some of the drivers tend to lean to the sides and especially to the right.

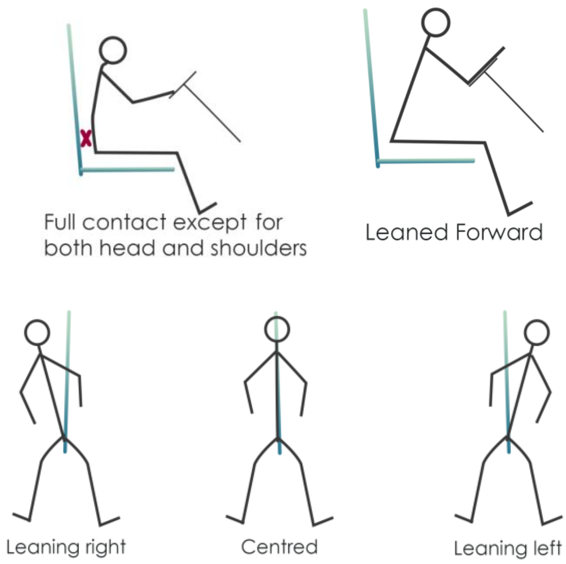


Figure 77, Driving in city

The city environment is the most demanding and the drivers adopt the most extreme postures (Figure 77). They have to be careful about the traffic, the traffic signs, they are more alert than in the highway, and they sit more upward and forward. They have full contact with the seat except from both the head and shoulders or they lean forward without any contact with the seat. They adopt the last postures when they feel tired or they have visibility issues. Moreover, they stay in the centre of the seat and sometimes they lean to the sides and mainly to the right, especially the short ones (which seemed to be related to need for visibility).

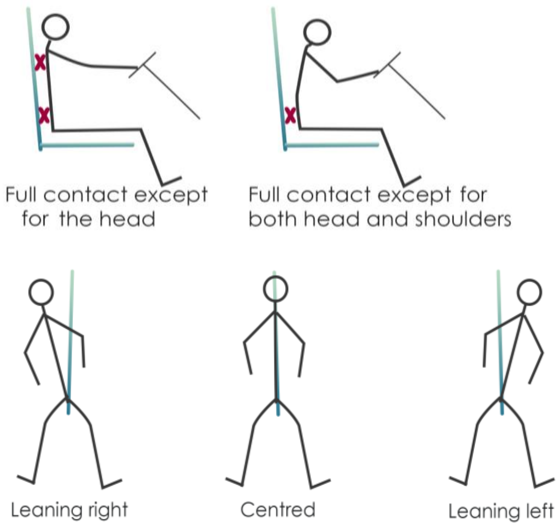


Figure 78, Left turns

During the left turns, the drivers stay stable on the seat and the degree of inclination is low. (Figure 78) They have full contact with the seat except from the shoulders and the head and they move their arms more. In general, they do not lean much to the left and there are also some drivers that either stay in the middle of the seat or lean to the opposite direction, the right. However, their behaviour and postures cannot be compared with the right turn where they tend to move a lot.

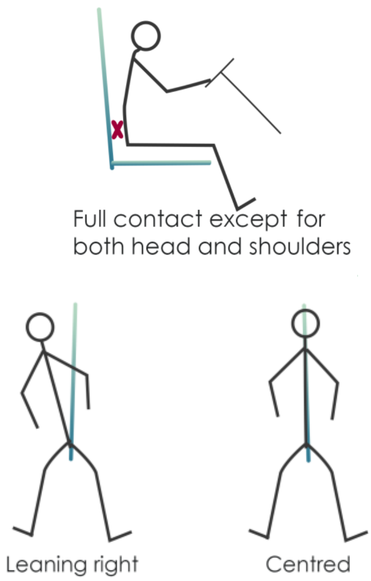


Figure 79, Right turns

While the drivers perform right turns (Figure 79), they clearly lean to the right direction and they do not stay stable in the middle. It is characteristic that they do not move so much forward, especially the taller ones are stable on the seat and they just move their head and arms. They are in contact with the seat but their heads and the shoulders are not in touch with it.

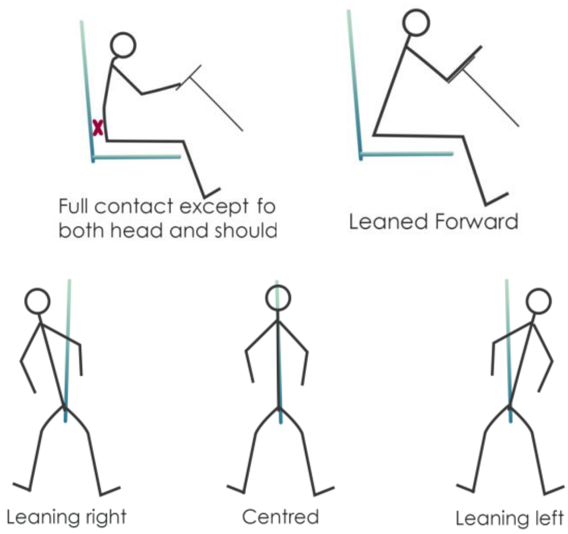


Figure 80, T-junctions

When the drivers perform the T-junction task (Figure 80), they lean forward and especially the short drivers in order to increase their field of vision. They have contact with the seat apart from their head and their shoulders. The T-junctions that were studied in the project were followed by left turns, and the behaviour of the participants varied. For instance, most of the drivers lean to the left side or stay stable in the middle of the seat but few of them lean to the opposite direction, the right.

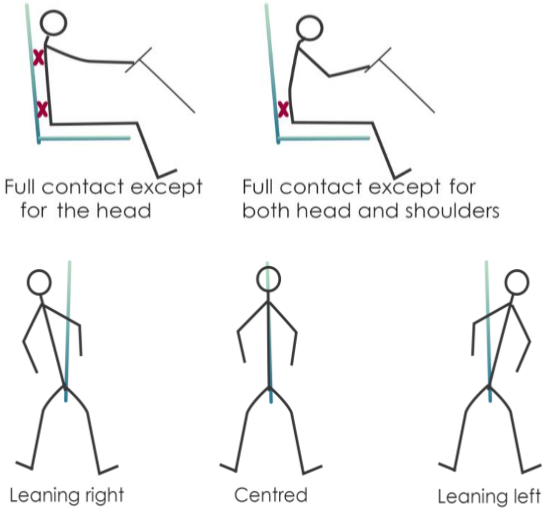


Figure81, Roundabouts

During the roundabouts, the drivers stay stable on the seat and just move their head towards the right direction. The short drivers tend to lean their torso forward. (figure 81)

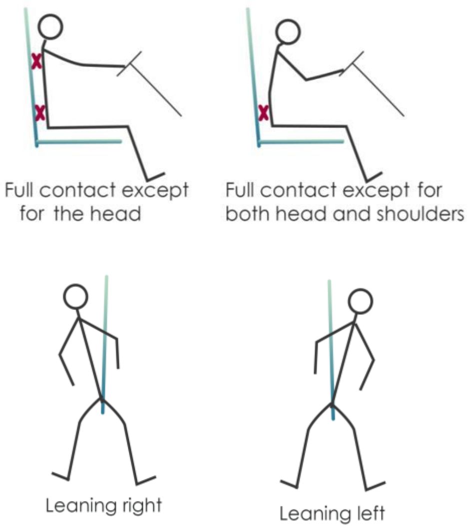


Figure 82, Intersections

Intersections are demanding for all the drivers. The drivers tend to lean forward and sometimes there is no contact with the backrest of the seat. Furthermore, there are some drivers that tend to lean towards the right direction even though they have to turn left.(figure 82)

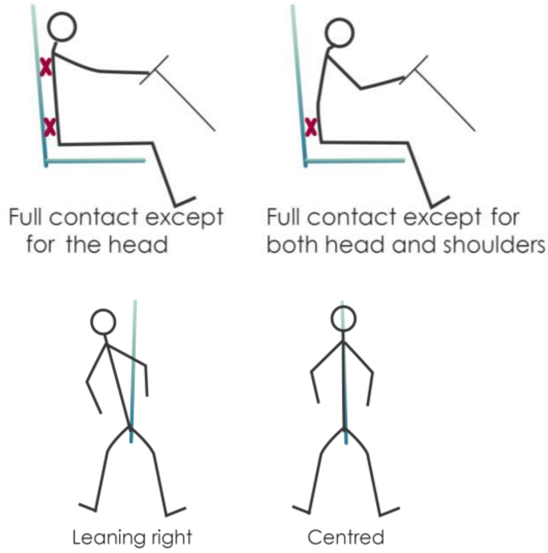


Figure 83, Low- speed manoeuvring

Finally, in low-speed manoeuvring, Figure 83, the drivers move in order to increase their visibility but they either remain in the centre of the seat or they move to the right direction. In addition to this, all the drivers sit backwards and their back and shoulders are close to the backrest of the seat.

9.2 Design Proposals

The proposals that follow are related to the cab components within the truck that were examined in the real truck, the driving simulator studies, and via the interviews that were held.
Concerning the seat, it should be more customized to the driver's physiology. The increased support for the lumbar, legs and back is crucial. Furthermore, the adjustment range should be increased backwards and upwards as seen in Figure 84.

Moreover, the seat cushion should be adjusted without leaving uncovered the space between the lumbar and the hip. The upper part of the seat is of great interest and should be redesigned in order to fit the short drivers, for supporting their neck and head. In general, a softer material is needed to be used for the seat cushion, because after a period of time it can feel hard and uncomfortable. The seat controls should have a more tactile feeling and be adjusted in a more representative and intuitive way. It would be ideal if the driver could be sure about the control he/she presses without having to look at it.

The size of the steering wheel should be reduced. It is unnecessarily big. Even more free adjustments than those that the neck tilt provides, should be available. The steering wheel should be able to go more backwards towards the driver's body and to adopt more angles for better visibility of the speedometer (Figure 85).

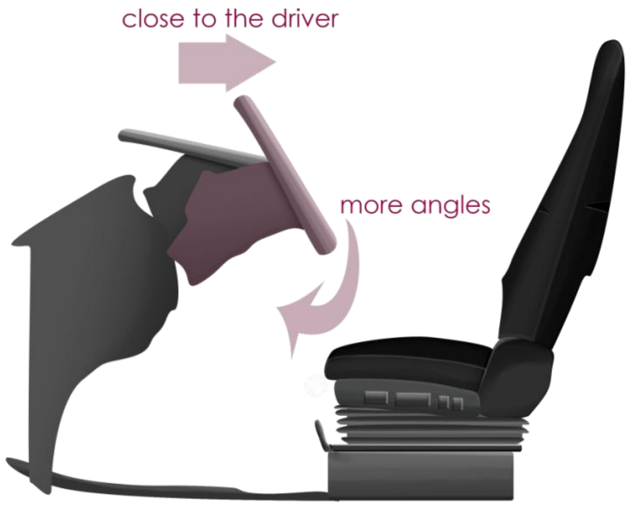


Figure 54, Steering wheel adjustment range

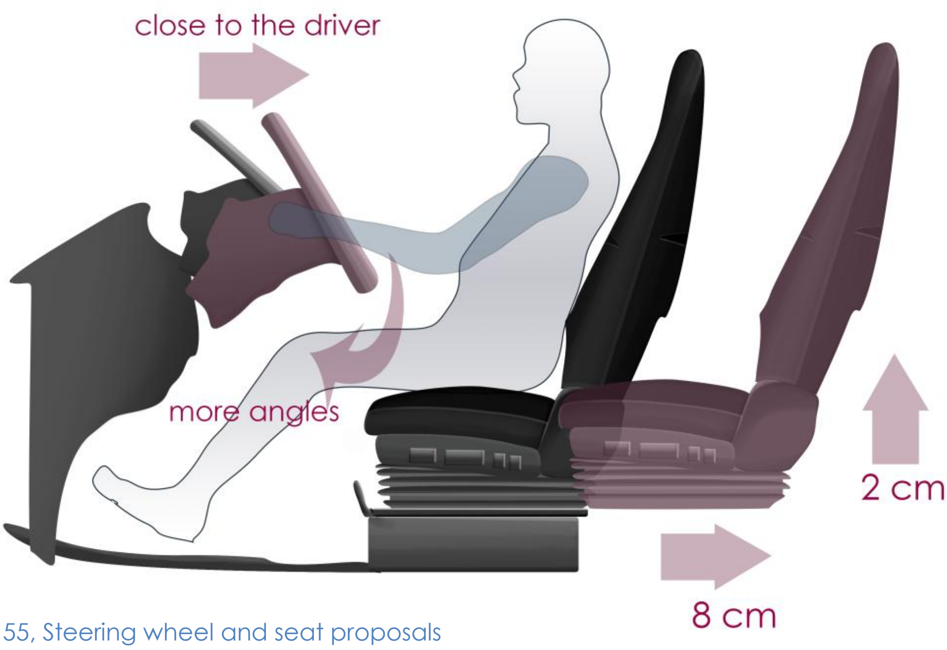


Figure 55, Steering wheel and seat proposals

Regarding the visibility of the surrounding environments, bigger window opening downwards would be a great solution for avoiding blind spots and for safer driving (Figure 86).

Figure 86, Window openings

10 Discussion

This chapter includes reflections and thoughts on the complete project. The discussion includes the final outcome of the project but also the process leading to this result. The discussion is concluded with recommendations of further work for completing that kind of studies.

10.1 Final Result

The project goal was to identify the key parameters that govern the driver's chosen driving postures, to examine the typical driving postures the drivers adopt and to identify the environments which provoke the most extreme postures.

The strength of this thesis work is that several case studies were performed, which enabled the collection of valuable data and then the cross-comparison of them. It was important to be able to support the outcomes with experimental studies and not only with literature. Moreover, the selection of the specific target group made the study not so ordinary, since there is only little investigation in short and tall people in other studies.

The final result was the answer of the research questions that were raised in the beginning of the thesis. The answer of the research questions was based on objective facts, through the establishment of original methods. Finally, some general improvements were proposed and illustrated, so that the cab of the truck could be more comfortable in the future, for as many drivers as possible.

10.2 Planning

This thesis work required a thorough planning as the case studies that were performed involved access to users and as a result the time plan could be easily exceeded.

The time planned for the 1st case study: questionnaires, was slightly modified so that as many drivers in the selected target group would answer the questionnaires. It was important to get a sufficient amount of answers for building the foundation of the problem. Also, the time for analysing the questionnaires required a short extension of the planned time, since the open questions of the questionnaires resulted in surprisingly varied answers, which were analysed and showed to provide valuable input.

The time plan for the second case study was followed without any delays. The third case study was the one which did not follow the initial plan and caused delays. The driving simulator was not delivered when it was planned, since software mistakes emerged, as well as mechanical problems with the components that were included in the physical representation. It was a risk to wait until everything would be perfect, so some compromising had to be done. As a result, it can be discussed if there would have been the possibility to get better results if this compromising could have been avoided. However, there was a risk of not finishing the thesis work in time and as a result it was tried to take advantage of the existing software and mechanical parts of the simulator that worked properly.

10.3 Execution

The implementation of this project and its planning has been successful, although some problematic situations occurred. However, it was tried to overpass the difficulties and not only the research questions were answered properly, but also some possible solutions were proposed.

One issue that could be discussed is that the field tests lasted for 70 minutes and the simulator tests lasted for 30 minutes. Both periods of time are not enough in order to identify possible signs of fatigue or discomfort, as in the literature it is mentioned that after 120 minutes of continuous driving one could identify signs of fatigue. Fatigue is highly connected with comfort/discomfort so it was important to be taken into consideration in the analysis. This aspect was tried to be answered through the questionnaires and the interviews and not that much through the videos and the observation.

Moreover, internal truck drivers were used for the 1st questionnaires and for the simulator studies. The results from the questionnaires were validated at some point from the questionnaires on blogs where drivers that had no relation to Volvo answered. Since the answers that were from external drivers were common with the internal drivers, we assume that the internal drivers answered as objectively as they could. In the simulator study, there was not the possibility to use external truck drivers because of the time limit of the thesis, the delays and the schedules that professional truck drivers have. As a result, internal truck drivers were used who under the assumption they were also objective in this study.

10.4 Methods

The three case studies that formed the thesis work have resulted in a user-centred approach and the examination of the environment of the cab as a system. The case studies that were used were complementary to each other, giving a gradual result that was confirmed and built cautiously.

The questionnaires, as a method, were an effective way to gain an understanding of important aspects related to driver's comfort. It was possible to understand the main areas that affect driving comfort, in relation to the drivers' height limitations of the target group. The interviews that were held in the 3rd case study gave the opportunity for further explanation of the parts that were not clear through the questionnaires in the 1st case study or needed further investigation.

The methods that were utilized to analyse the videos from the camera views in both real truck field tests and driving simulator tests were appropriate for understanding the driver's behaviour. The 4 cameras provided useful views, quite good videos, with a satisfying ability for analysis. It was crucial in both cases to know the exact part of the road on which the driver was driving, and this was possible through the installations. The application of Patrick signs was important for being able to have reference points in the truck and the driving simulator as well as on the driver's body.

One important aspect is that in the three case studies the aim was to involve the same truck drivers. To the amount that this was achieved for the three case studies, it enabled some confident results. Furthermore, it was important to have an equal sample of short and tall people, which was achieved in the three case studies. It was demanding especially to find short drivers but it was important at the same time.

The methods that were used to analyse the videos provided a holistic image of how the drivers react in specific driving situations and gave feedback about their driving behaviour. It was also possible to identify different patterns in their behaviour and understand how the height can influence their posture while they drive. The fact that the study with the real truck was performed before the simulator study enabled a more optimized way of working. The most crucial parts and the mistakes that should be avoided were taken into consideration, therefore everything worked smoother and better in subsequent studies.

On the other hand, English language could be a barrier for the truck drivers, since English was not their native language. It could be assumed that for some participants this affected their answers, but it was tried from the group members to provide them with further explanations. Therefore, it is assumed that most of the participants answered in the best possible way both via questionnaires and in interviews.

One specific question that remains is if the results are connected to the gender, since each of the extreme groups is represented by one gender. It was particularly demanding to find drivers from both genders in the selected target group.

Finally the comparison between the results of the field tests and the driving simulator test could have been affected by the lack of the traffic in the driving simulator scenario, which is an important factor when we investigate the posture of the drivers. Also, the lack of the neck-tilt technology at the steering wheel of the simulator, which was provided in the real truck, did not enable the same steering wheel adjustment opportunities. Moreover, it was impossible to drive during the same time period in the simulator as in reality, because the simulator cannot be used for long periods of time. As a result, a detailed comparison of the two study conditions maybe is not possible.

11 Conclusion

The following chapter summarizes the conclusions of the report.

The three case studies showed that the drivers adopt several postures depending on the driving situations and the tasks they perform. Moreover, all the studies showed that in city environment, drivers are sitting more upright looking often around the truck - to keep track of the surroundings. In general, they adopt a more alert position and this position is connected with their needs in the working environment and their interaction with the cockpit functionalities. In highway environment, they tend to have a leaned back posture and be more relaxed.

However the results about the low speed manoeuvring are different between the first case study and the other two. The first case study highlighted that during low speed manoeuvring the drivers choose a more upright position, to be able to actively looking around and they generally do many movements to increase visibility as they behave in the city environment. The other two case studies showed that almost all the drivers sit backwards and their back and shoulders are close to the backrest of the seat.

For the majority of the rest of driving tasks like the left turns, the T-junctions, both the second and the third case study resulted in the same outcomes however the studies with the driving simulator demonstrated that the degree of inclination of the drivers for every situation is lower compared to the studies with the real truck. Several factors affected this behaviour, for instance the duration of the studies at the driving simulator which was much less, the traffic in the driving simulator scenario and the existence of the steering wheel without the neck-tilt.

There are also other factors that can affect their behaviour and cause transition between the different postures. All the case studies illustrated that those factors can be limitations inside the cab and the working environment that prevent them from securing a clear field of vision and comfortable driving. In addition, the interviews both from the second and the third case studies as well as the observation during the driving simulator study indicated that there are several components inside the cab that prevent the target group to drive comfortably. The majority of the participants of the studies agreed that the seat, the steering wheel and the vision are crucial factors that affect their comfort. Furthermore, the interviews during the first case study pointed out more factors like the pedals and the reachability of the controls of the dashboard. However, the answers of the participants about those factors were contradictory and they could not be considered as important as the former factors.

In general, the tall people are less satisfied with the adjustment ranges that are provided inside the cab than the short. As a result, the tall people seem that they compromise their posture in order to fit inside the truck, while the short people are satisfied with the current available adjustments. The final proposals of the thesis project concerned the length and the height adjustments of the seat as well as the shape and dimensions of it. Another proposal is related with the controls of the seat. The drivers put extra emphasis on the position of the controls and they highlighted the importance of changing their shape and position in order to indicate their use and be more ergonomic in order to handle them easily. Another proposal referred to the adjustments of the steering wheel with more angles and the importance of the neck-tilt. In detail, the tall drivers would like to bring the steering wheel more backwards, close to their body, and the short drivers more angled so that they can all the parts of the dashboard. Finally both the short and the tall drivers agreed that bigger window openings downwards would help a lot their visibility.

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13 Appendices

13.1 Appendix 1: Project Planning – Gantt Charts

	1	2	3	4	5	6	7	8	9	10
To do:	week4	week5	week6	week7	week8	week9	week10	week11	week12	week13
planning report										
literature studies										
preliminary interviews										
analyzing preliminary interviews										
analyzing data from video										
simulation										
interviews										
analyzing data from simulator										
requirements-decision making										
ideation										
concepts										
final idea-modeling										
evaluation-simulation										

	11	12	13	14	15	16	17	18	19	20
To do:	week14	week15	week16	week17	week18	week19	week20	week21	week22	week23
planning report										
literature studies										
preliminary interviews										
analyzing preliminary interviews										
analyzing data from video										
simulation										
interviews										
analyzing data from simulator										
requirements-decision making										
ideation										
concepts										
final idea-modeling										
evaluation-simulation										
analyzing the results										
report										

13.2 Appendix 2: Long Questionnaires – Form & Responses

The questionnaires that were sent by email to internal drivers and employees were accompanied with a text explaining the purpose of this study, which follows:

We are two students from Chalmers University and we are doing our master thesis at Volvo Group Trucks Technology. We would like to investigate comfortable driving in the future and we would like your input in order to get an overview of the current situation, according to your experience. The aim of the Thesis project is to identify the key parameters that govern some of the chosen driving postures from the driver and the factors that cause transitions between significantly different categories of postures. We would like you to participate in this survey! NOTE: We will treat your individual answers as confidential information.

Thesis Background Research

Chatzopoulou Eirini, Vlassopoulou Aikaterini

We would like you to participate in this survey to give input for improving driving comfort in the future. NOTE: We will treat your individual answers as confidential information.

Questionnaire

I. Background Questions

I.a.

Name: --

Age: --

Weight: --

Height: --

Shoe size: --

Any particular physical problems (aching back, etc): --

I.b.

Years of experience: --

Kind of Volvo truck that you have experience: ---

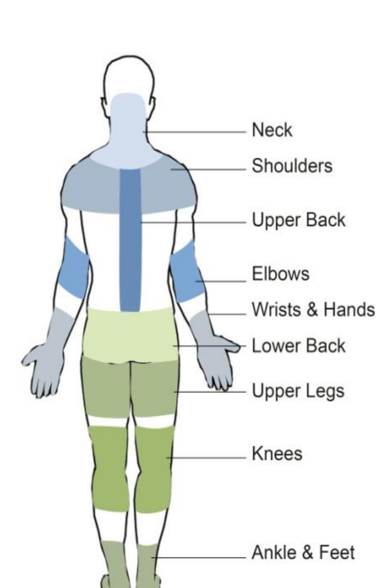
In what kind of driving situations do you have the most experience? (Choose from the list)

- ☐ Stop and Go
- ☐ Local
- ☐ Regional
- ☐ Long Distance
- ☐ Other --

II. Discomfort Rating (based on previous experiences from truck driving)

The image on the right illustrates the approximate parts of the body which are listed within the below table. Please reply, with the help of the image, in which areas you start to experience a certain level of pain / discomfort after a longer period of driving.

	No pain	Mild	Moderate	Severe	Very Severe	Intensely Painful
Neck						
Shoulder						
Upper Back						
Elbows						
Lower Back						



Wrists & Hands						
Upper legs						
Knees						
Ankle & Feet						
Overall						

III. Truck components

III.a Now we would like to know how much each of the components within the driver environment **influence your driving comfort**. You should answer according to your **general experience**, not as an evaluation of your specific truck. Please rate each component according to the following scale.

Not at all	Little	Moderate	Much	Very much	Extreme
1	2	3	4	5	6

	Rating	Comments
Seat		
1.Adjustment opportunities **2. Backrest** **3. Seat base cushion** **4. Seat suspension** **5. Others**	---------------- ---------------- ---------------- ---------------- ----------------	
Steering wheel		
1. Adjustment range **2. Gripping comfort** **3. Steering wheel**	---------------- ---------------- ----------------	

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angle **4. Steering effort** **5. Others**		
Instrument panel viewing conditions		
1. View of instrument cluster **2. View of dashboard controls** **3. View of secondary displays** **4. Others**	---------------- ---------------- ---------------- ----------------	
Pedals		
1. Reach for pedals **2. Accelerator operation** **3. Brake pedal operation** **4. Foot support for left foot** **5.Foot support for right foot** **6. Others**	---------------- ---------------- ---------------- ---------------- ---------------- ----------------	
Reach conditions		
1. Dashboard controls **2. Storages** **3. Controls in the radio shelf** **4. Door controls** **5. Others**	---------------- ---------------- ---------------- ---------------- ----------------	

Visibility of surroundings		
1. Forward vision **2. Vision to the left** **3. Vision to the right** **4. Via rearview mirrors** **5. Via close-up mirrors** **6. Others**	----------------- ----------------- ----------------- ----------------- ----------------- -----------------	
Provided space		
1. Leg room **2. Foot room** **3. Knee room** **4.Others**	----------------- ----------------- ----------------- -----------------	

III.b Are there other aspects influencing driving comfort that we have missed?

IV. Open Questions

1. Which factors affect the choice of your sitting posture? (Please list several)

----

2. How does the type of driving task (low speed maneuvering, city, highway), influence your driving posture when driving at a truck?

----

3. Have you got some clearly different postures that you alternate between while driving?

----

4. Which are the main improvement areas in the truck to improve your driving comfort even further?

----

5. Have you experienced higher levels of driving comfort in other truck brands / models? If yes, what was the brand and why was it better?

Thank you!

Answers

Some statistics from the questionnaires are represented in Table 7 and 8.

Table 4, Statistics 2

Women (target group)	Men (target group)	Participants shorter than 1.70 m	Participants taller than 1.85 m	Shortest participant	Tallest participant	Average experience	Average age
6	9	7	8	1.60 m	2.01 m	10.3 years	43 years

Table 5, Statistics 3

Average height short	Average weight short	Average shoe size short	Average height tall	Average weight tall	Average shoe size tall
1.65 m	65 kg	38	1.91 m	91 kg	45

In which areas do you start to experience a certain level of pain / discomfort after a longer period of driving? (15 answers)

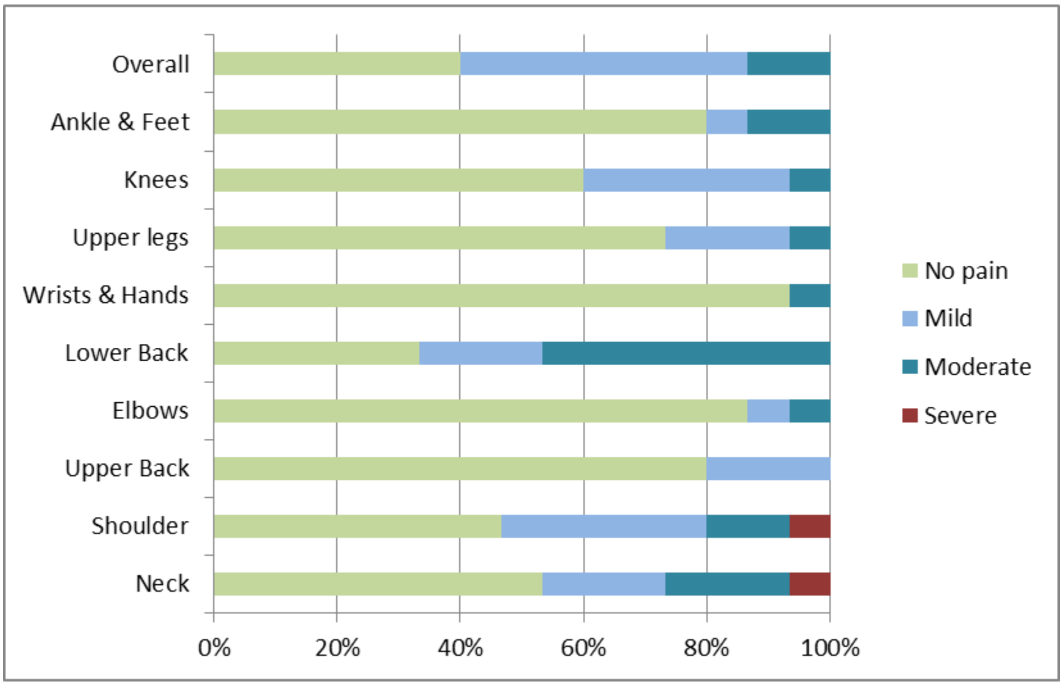


Figure 56, Discomfort rating results

How much each of the components within the driver environment influences your driving comfort? (10 valid answers)

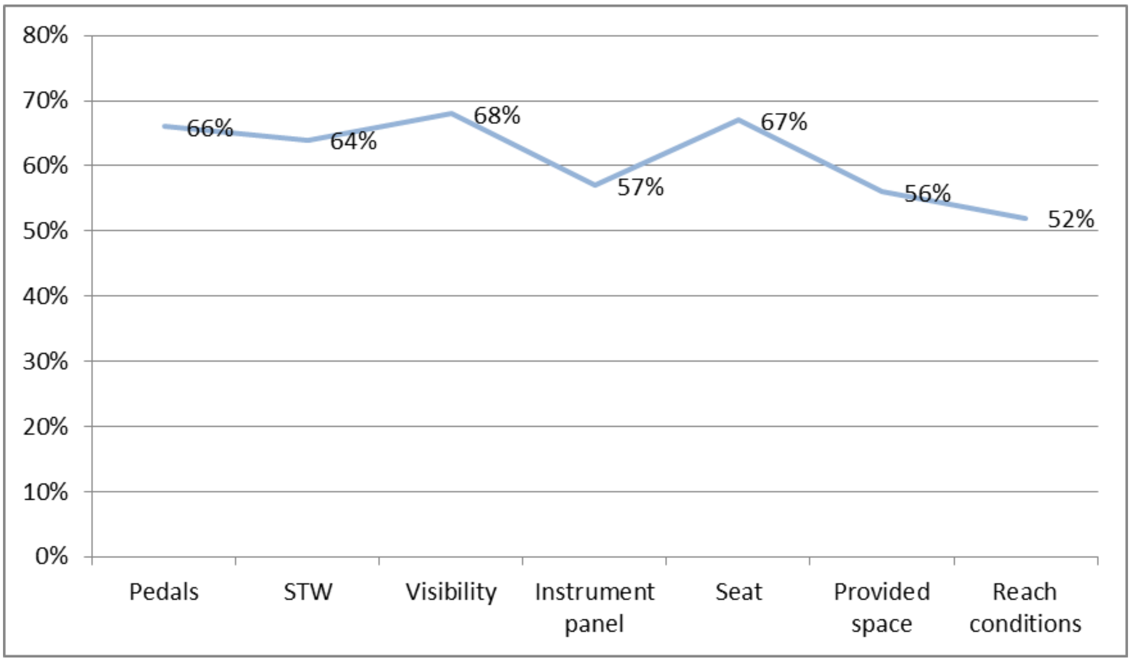


Figure 57, Factors that affect driving comfort - results

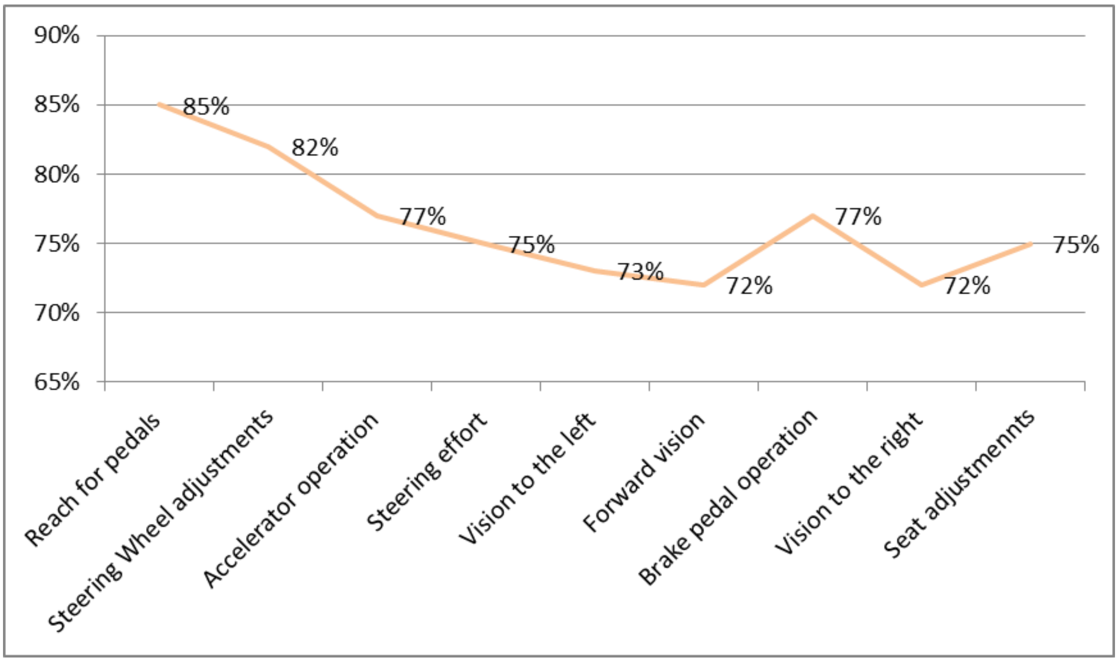


Figure 58, Specific component rating - results

Which factors affect the choice of your sitting posture? (Open Question – 15 answers)

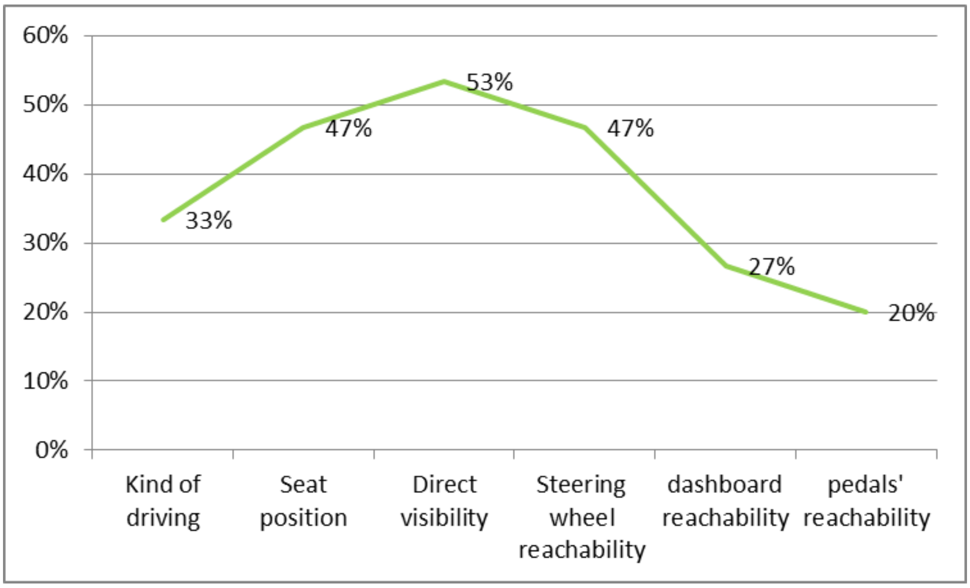


Figure 59, Factors that affect selection of posture - results

How does the type of driving task (low speed manoeuvring, city, and highway) influence your driving posture when driving a truck? (Open Question – 15 answers)

- 27% (4/15 participants): They do not feel that their posture is influenced by the driving task. (2 tall and 2 short)
- 73% (11/15 participants): They categorized their answers as follows.
- <u>City</u>:
  "I have more upright posture, I drive straight upwards".
  "I have no connection to backrest because I want to have clear vision through the window.
  "I am more alert. I want to keep track of the surrounding traffic and have easier and quick reach of controls."
- <u>Highway or country road</u>:
  "I usually adopt a more leaned back posture."
  "I sit more reclined and relaxed."
  " It is important that you can sit comfortably for a longer time and you don't get hurt in the neck or back etc."
- <u>Low speed maneuvring</u>:
  "I have to move my body more to see what's happening around me. "
  "I usually have a more upright posture and I actively look left/right for information about how close I am to the surrounding objects. "

Have you got some clearly different postures that you alternate between while driving? (Open Question – 15 answers)

This question was answered in the same way as the previous one from the most participants.

- 47% (7/15) of the participants categorized their postures in relation to the kind of driving
- 33 % (5/15) answered that they alternate the angle of the backrest, the height of the seat or the steering wheel during driving, just for the alternation
- 20% (3/15) answered no

Which are the main improvement areas in the truck to improve your driving comfort even further? (Open Question – 15 answers)

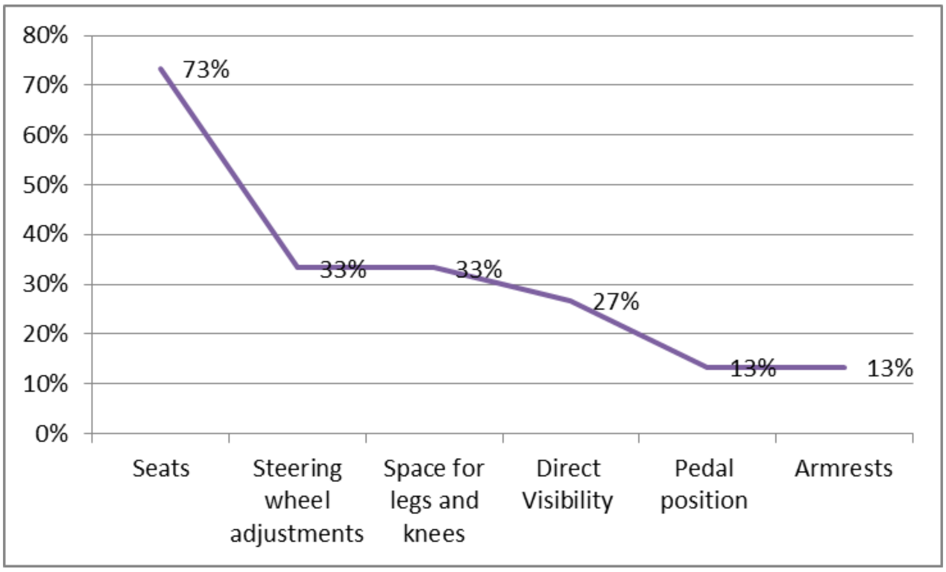


Figure 60, Main improvement areas

Have you experienced higher levels of driving comfort in other truck brands / models? If yes, what was the brand and why was it better? (Open Question – 15 answers)

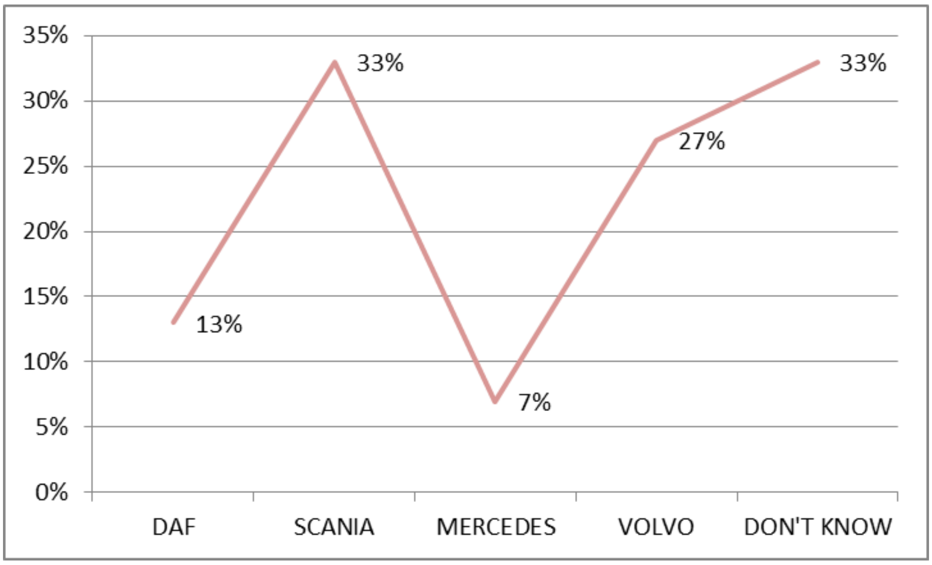


Figure 61, Competitors in comfort

13.3 Appendix 3: Online Questionnaires – Form & Responses

Form

An account was created in various drivers' forums were the following form was uploaded, accompanied with the same message that was sent through emails to the internal drivers. The link for this form was provided and then anonymously the drivers could answer to it. The responses were from many different nationalities.

Designing comfortable driving in the future

Gender

Age

Weight

Height

Shoe size

Any particular physical problems (aching back, etc)

Years of experience

Kind of Volvo truck that you have experience

In what kind of driving situations do you have the most experience?

- [ ] Stop and Go
- [ ] Local
- [ ] Regional
- [ ] Long Distance
- [ ] Other

Which factors affect the comfort while driving a truck?

- [ ] Seat
- [ ] Steering wheel
- [ ] Instrument panel viewing conditions
- [ ] Pedals
- [ ] Reach conditions
- [ ] Visibility of surroundings
- [ ] Provided space

Which factors affect the choice of your sitting posture?

- [ ] Fatigue
- [ ] Pain
- [ ] Climatic conditions
- [ ] Reachability
- [ ] Driving Situation(low speed maneuvering, city, highway)
- [ ] Vibration
- [ ] Vision
- [ ] Other

Have you got some clearly different postures that you alternate between while driving?

Which are the main improvement areas in the truck to improve your driving comfort even further?

Have you experienced higher levels of driving comfort in other truck brands / models? If yes, what was the brand and why was it better?

Submit

Never submit passwords through Google Forms.

100%: You made it.

Responses

Some statistics from the online forms are represented in Table 9 and 10.

Table 6, Statistics 3

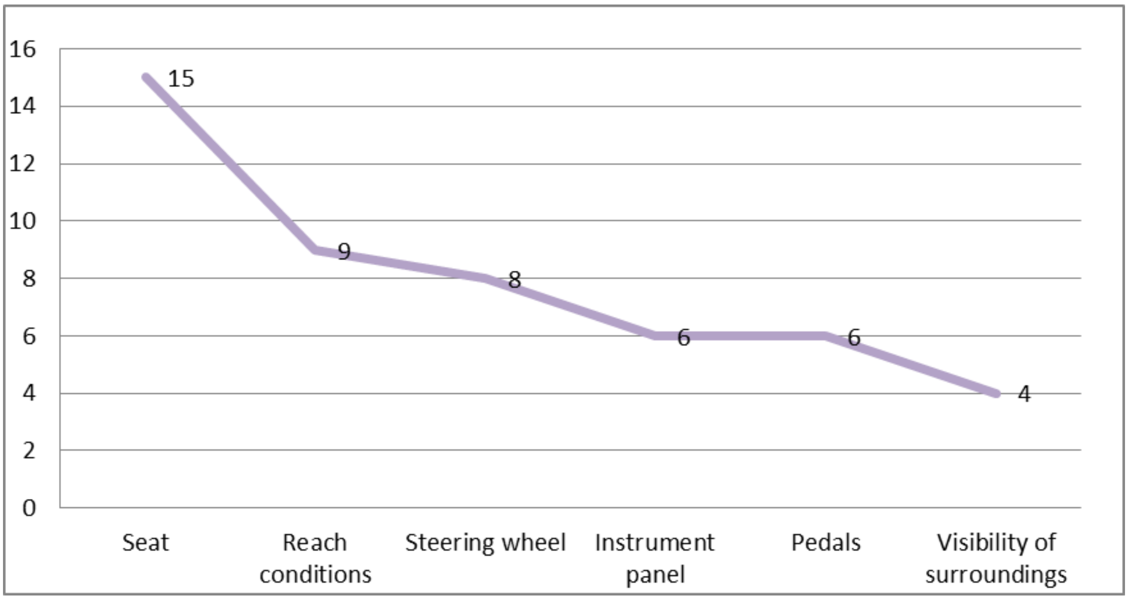
Women (target group)	Men (target group)	Participants shorter than 1.70 m	Participants taller than 1.85 m	Shortest participant	Tallest participant	Average experience	Average age
2	14	5	11	1.62 m	2.0 m	11.6 years	37.4 years

Table 7, Statistics 4

Average height short	Average weight short	Average shoe size short	Average height tall	Average weight tall	Average shoe size tall
1.67 m	74.8 kg	41	1.91 m	100.3 kg	45

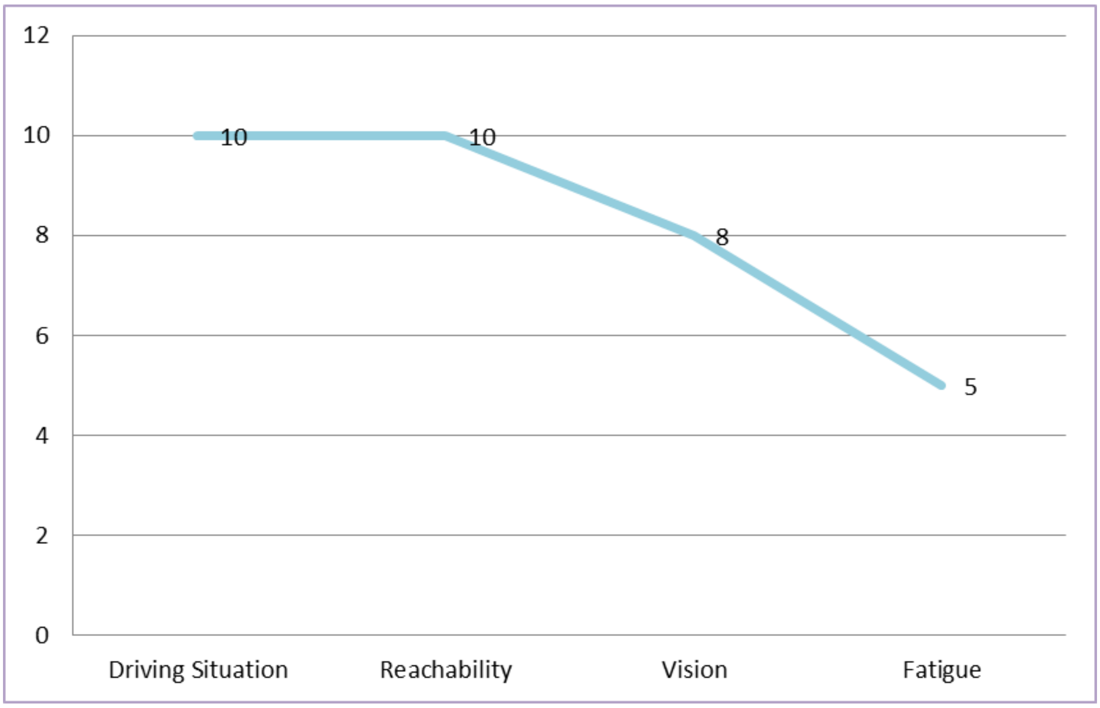
Which factors affect the comfort while driving a truck? (16 answers)

Table 8, Factors that affect comfort



Which factors affect the choice of your sitting posture? (16 answers)

Table 9, Factors that affect the choice of sitting postures



How does the type of driving task (low speed manoeuvring, city, highway), influence your driving posture when driving at a truck?

This question was answered in the same way as in the long questionnaires

Have you got some clearly different postures that you alternate between while driving?

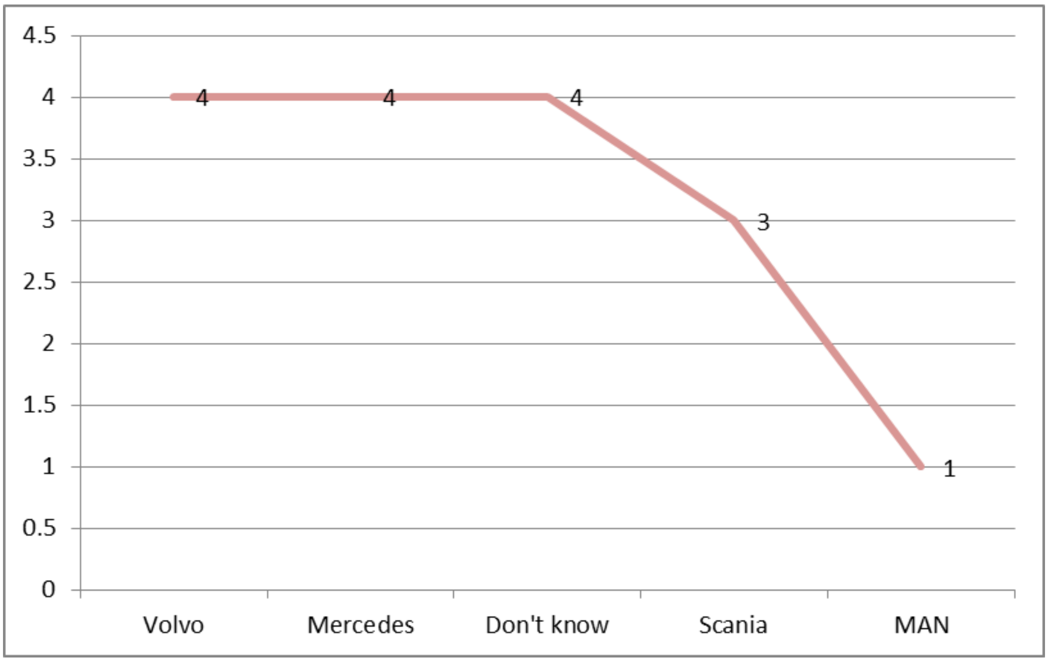
Most participants answered No or did not fill this question

Which are the main improvement areas in the truck to improve your driving comfort even further?

The component that was mostly referred was the seat, but each participant mentioned a different part of the latter. Other results cannot be obtained from this question.

Have you experienced higher levels of driving comfort in other truck brands / models? If yes, what was the brand and why was it better?

Table 10, Comfort in truck brands



13.4 Appendix 4: Results from comments on both questionnaires, divided into the tall and short group.

Here there are the most commonly mentioned comments from both questionnaires. Some statistics about the participants whose comments are included are presented in Table 14. The long questionnaires gave the opportunity to the participants to write more comments and express more themselves, but those comments were confirmed in a high amount by the blog questionnaires also. After each comment, the amount of the total participants that mentioned it is listed.

Table 11, Statistics about comments

Total Participants	Wrote at least one comment	Tall (>= 1.85 m)	Short(<= 1.70 m)
31	27	17	10

a. Seat

Tall

It is very important for tall drivers to adjust the seat easily **without extra movements (5)** or effort. The range of **the length adjustment (11)** should be **increased** because they need to move the seat more backwards in order to raise their comfort and they would also like to have **longer adjustment in the seat cushion (4)** to get more support to the upper legs**.** They also need the possibility to lock the **seat suspension** in some situations **(4).** Furthermore, they would like to have the possibility to **adjust the shoulder part (4)** and change the position of the **air-cushion (3)**. In general they need a seat that could **fit to their body dimensions (11),** especially **the backrest part**. Easier **in and out (4)** of the vehicle would be also appreciated, without having to change the position of their seat in order to get out the truck and then having to readjust it. **Longer seatbelt (2)** is also needed, so they can lean forward as long as they want to get full visibility (especially during driving in the city).

Short

Short people should be able to **lower their seat (10)** in order to get close to the steering wheel and be able to reach the floor and the pedals. The lower seat could help them additionally to **get in and out (5)** of the vehicle, which is also a problem for them. Usually they have to place their seat **really forward, which makes them not to have any free space around them (8)**, and diminishes the possibility to move their arms and legs without hitting anything**.** It is also really difficult for them to **reach the buttons (7)** and they would like to have **more adjustments** on both sides of the **backrest** on the sides of the seat. Furthermore, they don't feel **comfortable with the seatbelt (6)**, as short people have smaller shoulder breath and shorter torsos, generally and they feel that the seatbelts not only don't suit to them, but they are also uncomfortable. Finally, a more comfortable backrest support, which is lacking for short people especially on the sides, would be appreciated **(4).**

In general, both short and tall drivers would like a more **comfortable ventilated material (4)** with **high friction and less hard cushion (5)** at the base of the seat. Moreover, they really support the idea of the **armrest at both sides (5)** with the possibility of adjustable height for the elbows. Finally, an extra piece of **padding on the door ledge (2)** where their arms usually rest,, is one more suggestion.

b. Steering Wheel

Tall

The steering wheel should be **fully adjustable (11)** and tall people want to have the possibility to get it **further back**, closer to them **(5)**. It should **not** be so **horizontal (2),** as they have to bend a lot especially during low speed manoeuvring**.** They would like to put **less effort (7)** to manipulate it. Many tall drivers mentioned that Volvo has solved several problems by launching the last FH model, as it includes **VDS** which demands less effort and also the **necktilt,** which provides **wider range of adjustments** and increased **gripping comfort (7).**

Short

Short drivers need also a **fully adjustable steering wheel (7)** that allows several different **gripping possibilities (5)**. They highlight the significance of **reaching the steering wheel without having to adjust the seat in an uncomfortable way or in a way that diminishes their visibility (8)**. Usually, they have to place the steering wheel **too close to their stomach**, which is pretty uncomfortable **(5).**Many positive comments about **VDS** and **necktilt** were mentioned from this group also **(6).** Finally, two aspects that were highlighted, were the **material** and the **rim** of the steering wheel, which sometimes contribute to uncomfortable driving **(5).**

c. Visibility

Tall

It is really important for tall drivers to **obtain upwards and downwards visibility (8)**. In detail, they mention that their **upwards vision** is **disturbed** by the external **sun visor (5)** and makes them to change position and **sit lower (8)**. Moreover, they believe that they don't have a **clear field of vision** due to **the A-pillar** on the driver's side and the **location of the mirrors (6).**

Short

Short people face **many difficulties** with the visibility of the surroundings. Actually, they **cannot achieve a comfortable sitting (9)** posture with at the same time **having a clear field of vision (10)**. When they **adjust the seat lower,** so that they reach the pedals and steering wheel, they are **not able to see through the window and the windscreen (6)**. As a result, their common chosen posture is to seat in **one of the highest positions** to have good visibility, and they always **tilt the seat forward** to reach the pedals and floor **(5).** They also mention that their **forward vision is directly affected by the seat height and position (6)**. Almost always they have **to compromise their posture (9)** due to visibility, or they **move a lot back and forward**, especially in demanding road conditions. However, some claim that the new **FH** model provides them with **very good vision** at the front and the sides **(2).**

d. Pedals

Tall

Considering the difficulties tall people have with the pedals, they need **more upright support for the left foot (4)** and extra support for **the right foot (5)**. They also point out that there is little **space at the footrest (7)** and some of them would like to have the opportunity to **operate the vehicle barefoot (3).** They also mention that they need **adjustable pedals (5)**.

Short

Short drivers would prefer the vehicle to have **adjustable pedals (8),** in order to achieve a comfortable posture without influencing their v**ision through the windows and the windscreen**. They think that they the pedals are usually located really **high from the floor surface (6)** and they would like to have **more support in both their feet and space for rest (6).** This group also mentions the possibility to drive **barefoot comfortably (4).**

13.5 Appendix 5: Studies using the driving simulator

Simulator Test Structure

Introductory comments about the procedure

- Estimated time: 90 minutes
- Number of participants: 8
- 4 video cameras will be installed (side view and front view of the test driver; side view of chosen seat position and tilt; side view of chosen steering wheel position and angle)
- Device for voice recording during the interviews
- The measurements are going to have accuracy of a whole cm and they are going to be done by the same person for all the tests
- The instructions & questions are going to be provided by the same person for all the tests
- The method is going to be exactly the same for each participant
- Each driving condition is going to be announced some minutes before it is going to begin
- The speed limit should be recommended in the beginning of each session and before each driving condition. It is also important to advice each test driver to take it easy and drive as with a real truck.
    - 80-90 km/h highway driving and 50 km/h city driving
- The sessions are going to be performed in the same order for each test person
- The participants should not be leaded to specific answers in the asked questions. By sticking strictly to pre-formulated questions, this will be avoided.
- The drivers' performance is not going to be taken into account
- The awkward position that the seat and steering wheel are going to be adjusted is going to be same for tall and short people. Steering wheel maximum folded forward, seat in the highest and most forward position and with no tilt but backrest folded significantly backwards).

Purpose: To identify how often the driver changes posture in each of the 2 sessions and the amount of comfort they feel.

The procedure

1. Welcome the drivers and explain the aim of the study and the entire procedure that is going to follow
2. Initial **background questions** (we have already age, height and weight from the questionnaires).Fill in the paper with the scales.
   Name:
   Upper body length:
   Eye height above seat:
   Knee height sitting:
   Arm length gripping:
   Which is the distance that you drive per year?
3. **Familiarizing** phase
   - Present the different parts to the driver (seat, steering wheel, pedals, instrument panel, secondary display, dashboard, gear shift).
4. Advise the participants to drive and **react like in reality** and to follow all the safety rules (seatbelt, speed)
5. Inform them that they can stop the procedure whenever they want, if they don't feel well or for any other reason
   - Explain the procedure of stopping the vehicle

1st variation/session (driving for 25 minutes in total)

6. Prepare **1st set** of adjustment ranges *(FH dimensions)*
7. Adjust stw and seat in an awkward position (Steering wheel maximum folded forward, seat in the highest and most forward position and with no tilt but backrest folded significantly backwards.)
8. Ask the driver **to get seated in the driving simulator** (Best is to enter from the left as in a real truck and open the left TV screen as a door. Once seated, the TV screen can be put back at the intended angle. The views of the simulator will be according to the medium-size driver reference.)
9. Getting acquainted – advice to make **seat & stw adjustments to fit their body size and needs,** in relation to the driving conditions that will follow (starting with country side driving).The neck-tilt is locked so they cannot adjust the angle but only the length and the height of the steering wheel.
10. Ask the driver to look at the different **seat controls** and the **steering wheel adjustment control** and comment about them (main purpose to secure that they know how to make the adjustments and for us to have feedback about the controls)
    - Ask them if they know all the functions of the adjustment controls of the seat
    - Which ones they use more often
    - Which one is the most difficult to use
11. Ask the driver to choose his/her most **usual position for driving** (adjust stw and seat). **Read out the chosen seat positions** in relation to the reference position and calibrate the views accordingly by offsetting the eye-point via the editor. NOTE: Here

the information about the "Eye height above the seat" will also need to be used as input in relation to the corresponding value for the medium-size driver.

12. Ask the driver to adjust the **mirrors** (show how they are working)
13. Explain the procedure of starting up a vehicle
14. Drive on the **county-side / in the city** (including parking maneuvers)
15. Drive in the **city** (including parking maneuvers) / on the **country-side**
16. Ask them to **stand up from the simulator** and offer them a seat separated from the driving simulator where they can relax for a while.
17. **Interview questions 1**
    - Are the chosen postures the **same typical positions** that you adopt in reality if you have the chance and do you alternate between them? (Input if the simulator is representative while changing postures)
    - How would you **rate your perceived comfort** in city/high way/maneuvering?(written scale from 0 to 6 for each of the 3 conditions)
    - Are you usually able to adjust what you want during driving? Which **component(s)** would you like to adjust **while driving if it was easier**?
        - If you would like to adjust the seat, which specific part of the seat would you like to adjust?
        - If you would like to adjust the steering wheel, in what way would you like to adjust it (position, angle, etc)?
        - If you would like to adjust something else, what and in what way?
    - Do you usually adjust the truck components in a different way in city compared to for low speed maneuvering? (Outcome: If there is a difference between low speed maneuvering and city environment)

2nd variation/session (driving for 25 minutes in total)

18. Prepare **2nd set** of adjustment ranges (Free adjustments, remove obstacles)
19. Adjust stw and seat in an awkward position (exactly same position as before)
20. **Explain** for the driver that the adjustment ranges of the steering wheel and seat are proved to be crucial for maximum driving comfort according to the questionnaire results and this time more adjustment freedom is provided.
21. Ask the driver to **get seated in** the driving simulator (Best is to enter from the left as in a real truck and open the left TV screen as a door. Once seated, the TV screen can be put back at the intended angle.)
22. Getting acquainted – advice to make **seat & stw adjustments to fit their body size and needs in relation to the driving** conditions that will follow(starting with country side driving).Ask the driver to adjust the **mirrors**
23. **Drive** on the county-side / in the city (including parking maneuvers)
24. **Drive** in the city (including parking maneuvers) / on the country-side
25. Ask them to **stand up from the simulator** and offer them an another seat
26. **Interview Questions 2** (Main purpose to compare with the previous session, which is close to reality)
    - Do you think that the new adopted postures are more comfortable than the first ones?(answer for the 3 conditions)

- How would you rate comfort in city/high way/maneuvering?(written scale from 0 to 6)
- Would you think that if you had these adjustments, the driving task could be more comfortable?

27. Final Questions

STEERING WHEEL

- Do you have experience with Volvo Dynamic Steering. If yes, what is your opinion and in which environment is it mostly useful?
- How useful is the pedal for adjusting the steering wheel during driving and would you prefer if the steering wheel was adjusted in another way?
- Are you satisfied with the gripping comfort that the steering wheel provides?
- What improvements would you like the steering wheel to have?

SEAT

- In which amount do you think the seat design supports your body and fits to your dimensions?
- Which part of the seat should be improved? (Top 3)
- Are you satisfied with the positions of the current seat adjustment controls?
- Which do you think is the best position for the adjustment controls(e.g. current one, both sides of the seat, other position on the seat, close to gear shift, on the steering wheel, on the dashboard, via the secondary display)

VISIBILITY

- Are there any specific parts of the truck that obstruct your needed field of view?
- If the truck had bigger window openings (windows and windscreen), would this improve your visibility?

PEDALS

- Do the seat and steering wheel adjustments contribute to reaching the pedals?

SIMULATOR

- How was your experience with the driving simulator?
- What is close to reality and what is not?

28. **Thank** them for participating and offer them the 2 free tickets for cinema.

29. Ask them if they wish to participate in the **final evaluation** that will follow in one month, for a shorter amount of time.

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