Evaluation of the Manikin Building Function in eM-RAMSIS when Using Motion Capture

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Abstract

This thesis project was formulated by Volvo Cars to find an answer to the question if an investment in a manikin building software was necessary or if the existing manikin eM-RAMSIS could produce valid results when using Motion Capture data to guide it. Motion Capture is a system for recording an objects motion and transforming it to a digital form which can be utilized to guide the motions or postures of various digital objects, in this case computer manikins. A computer manikin is a digital human model and has all the characteristics of a human: joints that are restricted to movements in only some directions, hands that can grasp things etc. These manikins are used by Volvo Cars to simulate working postures for the assembly workers who will work on the assembly lines of future car models. The manikins have been positioned after the best knowledge of the simulation engineer using mouse and keyboard. However with this new technique it is possible to record the actual position of an assembly worker in the Motion Capture lab.

Research conducted on the subject of Motion Capture and manikins show that it is crucial that the manikin closely resembles the person recorded. The manikin available for simulation engineers on Volvo Cars is eM-RAMSIS who only has three possible adjustments: length, sitting height and circumference. Thus the question arose whether eM-RAMSIS could produce valid results or not.

Three tests were originally carried out to find an answer to the question. The first test was aimed at examining the markerset used and verifying it, the result being to stick to the original markerset of 42 markers. The second test was designed to try to find some postures where the manikin encountered trouble and the postures identified were further analyzed and used as input in the design of the main test. This third test was performed by a test group of eleven, six female and five male participants of different anthropometry. The test consisted of different stretching and twisting tasks. The one which caused the manikin the most problems was reaching forward to the maximum while leaning forwards supported by a table frame. This task was extensively analyzed, taking the manikin to a virtual table and measuring how far it could reach and comparing this with the values from the test session. In general the manikin reached shorter than the test objects, in some cases up to 20 cm. Since there were many possible sources of error in the main test it was decided to do a supplementary test where the variables were cut down to a minimum. The position of the feet was exactly marked out on the floor and carefully measured against the table frame. For measuring of the reaching distance a cord with a stripe running on it was fastened on the table frame. This making the fingertip of the test object identified in three dimensions at the extreme of the motion. The test object was accurately positioned on the markings for the feet before the recording started.

The analysis of the supplementary test showed the same behavior as the previous test: that the manikin could not reach as far as the actual person. A measurement showed that the manikin had longer arms than the test objects. It would appear that the manikin has some built in limitations as to how it can move and be positioned. When reaching far a human lets the shoulder follow the arm forwards and also twists the back to reach even further, this behavior can not be mimicked by the manikin when using Motion Capture data.

To be able to answer the question whether the manikin created with Human Builder would produce better results comparing studies will have to be performed and has not been performed since the software was not available during the course of this thesis project. There has been no behavior observed where it could be determined that it would not have occurred with a more anthropometrically correct manikin.

The recommendations which will conclude this project are to do a comparison study using manikins created in Human Builder, to utilize all settings available for the eM-RAMSIS manikin, to unmark markers to instantly create a better manikin posture, to move the Motion Capture cameras when using many props to ensure a better data collection and using additional camera views to collect more photographic material that can be used as reference for judging the manikin posture.
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1 Introduction

This chapter covers the reasons for this project being formulated along with the limitations and time plan.

1.1 Background

The MERA Program (Manufacturing Engineering Research Area) is being conducted in co-operation between the government and regional research founders together with the automotive industry. The overall aim of the program is to increase the competitiveness of the Swedish automotive industry by working for the long-term improvement of research environments in fields relating to production technology and for the implementation of new and existing knowledge in industrial applications (VINNOVA, 2006). The MERA project has recently invested in Motion Capture equipment, which placed in a lab on the premises of Volvo Car Corporation, VCC, in Torslanda, Gothenburg. This equipment will be used for positioning of computer manikins and will be used as a compliment to traditional manual positioning of manikins in simulation software. The simulations in which the equipment will be used are of assembly work for future car models currently being developed. The simulations are aimed at evaluating the future working positions for the assembly workers and to ensure good working positions.

Previous studies have shown that using manikins of a different size than the recorded person when using Motion Capture data should be avoided. Chiang et al (2006) have looked into the problem and recommend that if one is interested in the results of a 5th percentile woman then a 5th percentile woman should perform the task.

Motion Capture produces a model that represents the test objects motion and can be connected to a manikin software, in this case eM-RAMSIS\(^1\). However, since eM-RAMSIS only have a few adjustable anthropometric variables, the creation of a manikin that accurately resembles the test object is impossible. This may cause difficulties and odd behavior from the manikin as the body construction of the test object may differ a great deal from the manikin.

1.2 Aim and objective

The purpose of this project was to investigate how well the eM-RAMSIS manikin resembled and acted like a test object when using Motion Capture data to guide it. More explicitly it was to investigate whether the anthropometric data tool available in eM-RAMSIS was good enough to get a valid result when using Motion Capture data to guide the manikin motion. The investigation would result in a recommendation for investing in an additional software for creating manikins, called Human Builder, or not and how to tackle the manikin problems when using Motion Capture data.

1.3 Delimitation

The extent of the master’s thesis was limited by a project time set to 20 weeks, which would include literature studies, design of experiment, tests, analysis and thesis paper writing.

During the project only optic Motion Capture equipment has been used from Motion Analysis. The equipment included the software EVaRT version 4.7, 10 Hawk digital cameras and Motion Analysis Eagle Hub 3. This was the system available at Volvo Car Corporation. The results were based on the eM-RAMSIS manikin and therefore only valid for this manikin.

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\(\text{eM-RAMSIS is an integration of the manikin RAMSIS in the virtual environment of eM-Human from Tecnomatix, UGS. RAMSIS is short for Rechnergestütztes Antropologisch Mathematisches System zur Insassen- Simulation, developed by Human Solutions.} \)
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1.4 Time Plan

The time plan for this project has been a living document, and has continuously been reviewed and updated. The time plan is presented in short below.

- Project start: Wednesday, September 13, 2006
- Literature studies: September – mid October, 2006
- Introduction in eM-RAMSIS: September, 2006
- Introduction in EVaRT: First weeks in October, 2006
- Data collection period: mid October – mid November 2006
- Analysis period: mid November – December 2006
- Final editing of Thesis paper: January 2007
- Presentation: Mid February, 2007

The thesis paper has been written during the course of the project and one day each week was used for writing only. To document the work progress, daily notes were taken as well as visual documentation of different kinds.
2 Theory

The theoretical background for the different methods used will be presented in this chapter. This has the purpose of giving a basis and scientific context for the methods used.

2.1 Computer Aided Ergonomics

Today, most manufacturing companies are facing the same problem: the human element is not being considered early or thoroughly enough in the design process. This have a devastating effect on cost, time to market, quality and safety according to UGS (2006).

With simulation and computer aided ergonomics the ability to predict risk of injury associated with designs early in the concept phase can lead to better products that provide a safer interface for the operators and their work places. Godin and Stephenson (2006) claim that computer aided ergonomics and digital human modeling give the ability to reduce engineering design time, reliably test parts and reduce time to market, all of which will result in large savings.

The software provides the opportunity to use standardized evaluation methodologies to systematically vary system characteristics or human capabilities to determine impact on design. Just as a scientist would use experimental methods to establish cause and effect relationships in research, the ergonomic engineer can use digital human modeling to systematically vary both the environment and human characteristics to empirically investigate vehicle system design or working environment.

2.1.1 Digital Human Model – Manikin

A digital human model, usually called manikin, is a three-dimensional computer model of a human being. The manikin tools are mainly used for visualization that provides information about reach, field of view and body postures but also for analysis such as load ergonomic and comfort in car seats according to Sjöberg and Sundin (2004). Throughout the years the manikin has developed from an angular robot with few joints and details to a detailed model which bears an ever increasing similarity to the human being.

Sjöberg and Sundin (2004) also describe how the development during the years has resulted in two main types of computer manikins. One group (eM-Human, Ergoman and others) has its roots in tool development for solving technical problems such as time consumption and need of space during work space and machine design. The ergonomic aspects have been taken into consideration afterwards. The second group (eM-RAMSIS, Jack and others) has its starting point in the ergonomic aspects. A well developed representation of the human being and further development has been done, not only to be able to use the program on technical problems but also to address professionals with need of a tool for specific evaluation on human activity.

The greatest advantage of using a manikin for ergonomics is the multitude of biomechanical, physiological and anthropometric data that is available. The use of digital human models within the production development is exciting for ergonomists and engineers according to Godin and Stephenson (2006).

There are several different ways to get the computer manikin in an accurate position. The most common way is to use mouse and keyboard. Another method is to use a posture library which is useful in automotive vehicle interior development. With some manikins it is also possible to manipulate the manikin with inverse kinematics. When one joint is moved, the remaining joints in the system are controlled with the inverse kinematics algorithm. For example, when the hand of the manikin is moved the upper body and arm follows like links in a chain. A quite new technique is Motion Capture, where a test objects motion is captured and applied to a manikin. This produces a very natural manikin position. One important function is the possibility to change anthropometric data, the body dimension, of the manikin. This is useful when testing products and work spaces for different body types.
2.1.2 Manikin software

There are a several manikins used in the simulation community. The following part will cover two of the most commonly used manikins, Jack and eM-RAMSIS.

Jack

The center for Human Modeling and Simulation (2006) describes this software as a detailed human model which includes realistic behavioral controls, anthropometric scaling, task animation and evaluation systems, view analysis, automatic reach and grasp, collision detection and avoidance, and many other useful tools for a wide range of applications. Jack is product from UGS.

In the software it is possible to choose various types of manikins. For example: Large, medium and small Japanese manikins. Jack has also a corresponding female manikin called Jill. They can both be presented as standard manikins of the 1st, 5th, 50th, 95th and 99th percentile. To customize the manikin it is possible to enter specific values for 26 anthropometric measures.

Jack uses real-time inverse kinematics to determine the position of linked segments and joints when one body segment is moved manually. It is also possible to control Jack with mouse and keyboard, prerecorded postures and Motion Capture.

eM-RAMSIS

RAMSIS was developed by Human Solutions in cooperation with the automotive industry in Germany. The main cause was to ergonomically analyze and design automobile interiors. RAMSIS is one of the leading CAD-tools for ergonomic analysis and design of vehicles and working places. More than 70% of all automobile producers are now using it according to Human Solutions (2006). eM-RAMSIS is an integration of the manikin RAMSIS, from Human Solutions, in the virtual environment of eM-Human from UGS.

As in Jack, it is possible to choose various types of manikins in eM-RAMSIS. There are 90 statistically secured anthropometric types per population and a physiological replication of more than 100 joint angles. The anthropometric data is based on measurements performed on over 6000 people of different age and gender in Germany as stated by Johansson and Åhström (2004). To customize the manikin there are five settings; gender, length, corpulence, proportion and age group. They can be adjusted according to the following:

- **Gender:**
  - Female
  - Male

- **Length:**
  - very short
  - short
  - medium
  - tall
  - very tall
  - Specific value: 1340-1955 mm

- **Corpulence:**
  - slim waist
  - medium waist
  - large waist
  - Specific value: 522-1190 mm

- **Proportion:**
  - short torso
  - medium torso
  - long torso
  - Specific value: 702-1028 mm

- **Age:**
  - common (18-70)
  - young (18-29)
  - middle (30-49)
  - old (50-70)

Experiments of individual actions have resulted in a position library. This enables eM-RAMSIS to automatically calculate the posture for each task including collision detection, grasp posture and body balance. UGS (2006) stated the possibility to perform ergonomic analyses, such as OWAS and NIOSH, sight analysis and reach ability studies with eM-RAMSIS. Users can also analyze difficult-to-access or extremely cramped working environments, special positions of the worker (e.g., lying down, kneeling, bending, etc.) and hard-to-see assemblies from an ergonomic point of view.
2.2 Motion Capture

Motion Capture is a technology for providing an accurate digital representation of a subject's motion. This technology is utilized in game development, film industry and engineering for instance. The data can be used to guide the motion of a geometry, usually a digital human model or some other character. Figure 1 shows the different steps in the Motion Capture sequence with an optical Motion Capture system. Furthest to the right the recorded subject is seen with reflectors attached, then the view seen in the Motion Capture software: a cluster of dots and the two figures on the left shows the result when the Motion Capture data is applied to a manikin and a 3D-geometry, in this case a robot.

![Image of Motion Capture system](image)

*Figure 1. The different steps in an optical Motion Capture system. Picture from Wikipedia (2006).*

**Optical Motion Capture systems** use video cameras to track the motion of reflectors attached to joints and other parts of the subject’s body. Three to 16 (or more) cameras are necessary for full-body capture. Reflective optical Motion Capture systems use Infra-red (IR) LED's (light-emitting diode) mounted around the camera lens, along with IR pass filters placed over the camera lens.

Optical systems use the reflectors illuminated from strobes on the camera to triangulate each reflector from its relative location on a 2D map. Problems often occur during the tracking process, including swapping of markers, noisy or missing data and false reflections. Software has been developed to reduce problems from marker swapping since all markers appear identical. Unlike active marker systems and magnetic systems, passive systems do not require the user to wear wires or electronic equipment. Passive reflectors are usually spheres or hemispheres made of plastic or foam 3 to 25 mm in diameter with special retro reflective tape.
Magnetic systems calculate position and orientation by the relative magnetic flux of three orthogonal coils on both the transmitter and each receiver. The relative intensity of the voltage or current of the three coils allows these systems to calculate both range and orientation by meticulously mapping the tracking volume. Useful results can be obtained with two-thirds of the number of markers required in optical systems; one on the upper arm and one on lower arm for elbow position and angle. The markers are not occluded by nonmetallic objects but are susceptible to magnetic and electrical interference from metal objects in the environment, like rebar or wiring, which affect the magnetic field, and electrical sources such as monitors, lights, cables and computers. The wiring from the sensors tends to preclude extreme performance movements. The capture volumes for magnetic systems are dramatically smaller than they are for optical systems.

Mechanical Motion Capture systems directly track body joint angles and are often referred to as exo-skeleton Motion Capture systems, due to the way the sensors are attached to the body. A performer attaches the skeletal-like structure to their body and as they move so do the articulated mechanical parts, measuring the performer’s relative motion. Mechanical Motion Capture systems are real-time, relatively low-cost, free-of-occlusion, and wireless systems that have unlimited capture volume. Typically, they are rigid structures of jointed, straight metal or plastic rods linked together with potentiometers that articulate at the joints of the body (Wikipedia, 2006).

Field of application

Game development and the movie industry are the largest markets for Motion Capture, where the technology is used for recording motions of for instance soccer players or sword fighters. This method gives the characters in the game a natural pattern of movement and decreases the development time and can also be used for creating extras in scenes that require a crowd.

Meta Motion (2006) describes how biomechanical analysis for rehabilitation purposes relies extensively on Motion Capture for its ability to produce repeatable results. Motion Capture can be used to measure the extent of a client's disability as well as a client's progress with rehabilitation and to effectively design prosthetic devices. If the recorded motion is applied to a digital human model it is possible to evaluate working postures, reach zones and visibility in for instance enclosed spaces such as car interior or an aircraft cockpit.

2.3 Ergonomics- Human Factors

Ergonomics is the science of people in work; the interaction between human being and work instrument. Characteristic for ergonomics is the combined knowledge of biology, technology and psychology in the analysis of the human-tool interaction as described of NE (2006).

The Ergonomic Society of Sweden (2006) describes ergonomics as being concerned with the adjustment between people, things they perform, items they use and the environment they work, travel and play in. This means that difference in size, strength and ability to handle information have to be taken into consideration for a wide range of users.

There are several subgroups of ergonomics and one worth mentioning here is load ergonomics. NE (2006) explains this field as how work postures, work motion, physical load and other circumstances influence muscles and joints. Heart, blood circulation, sense organs and central nervous system are also influenced by the physical and mental load. According to the Swedish Work Environment Authority (2006) almost two thirds of all reported work related illness, of both men and women, arise from different kinds of overload. The main causes are heavy lifting, monotonous elements in the daily work and the combination of mental and physical stress.
2.4 Anthropometry

Anthropometry is the study and measurement of human physical dimensions aimed at understanding human variety according to Roebuck (1995) and Workspace health, safety and compensation commission of Newfoundland and Labrador (2006). The applications of anthropometry are numerous but Peacock (1998) describes the primary industrial areas of usage as visualization, plant layout, workspace layout, fit-reach-access assessment, and visibility examination. Other areas worth mentioning are medical practice, clothing fitting and design evaluation.

Anthropometry also includes segment masses, the centers of gravity of body segments, and the ranges of joint motion, which are used in biomechanical analyses of work postures. Biodynamics is defined by WorkRite Ergonomics (2006) as the study of the effects of internal and external forces on the human body in movement and rest.

Products and work stations can be developed for a special person or a population defined by for instance economy, interest, sex, age, functional disability or size. Statistical data of the distribution of body dimensions in the population are used to optimize products. The statistical distributions change with changes in lifestyle, nutrition and ethnic composition of the population, and require regular updating of anthropometric data collections according to Wikipedia (2006).

2.4.1 Gathering anthropometry data

Measuring usually involve three or more postures, typically one standard standing posture, one upright sitting posture, and special postures that permit maximum reach measurements of the arms and legs. Roebuck (1995) recommends using standard measuring methods when possible and when not possible he recommends describing the method used accurately for future reference. Survey reports should include tables of summary statistics, graphics, and text to explain how dimensions were obtained, what instruments were used and what the intent of each measurement was, i.e., what dimension was desired. Other important things to include in survey reports are descriptions of the methods used to select subjects, demographics of the resulting sample and descriptions for marking or finding landmarks.

2.4.2 Measurement techniques

There are different kinds of measurement techniques that can be used depending on what body measurements are required. Manual measurement is the most common method used due to the simplicity and the cheap and easy-to-come-by equipment, often consisting of a tape measure. When measuring standing subjects they should stand upright looking straight ahead, arms to the side and barefoot. For measurements of sitting subjects they should sit upright with knees at right angles, looking straight ahead with arms to the side and a 90 degree bend in the elbow. A floor or a wall provides a reference plane relating all heights to either the floor or the level, flat top of a table or chair. Breadths across the body (shoulders, hips and head) can be referred to an implied medial plane of symmetry. Accuracy sufficient for engineering purposes can often be achieved with simple scales or grid markings on a wall, floor or table. Circumference and arcs are usually measured with flexible tape, Roebuck (1995).

Photography and video imaging are among the most common and well known of the modern indirect methods. Since the distances measured are the actual distances in the photographs, Roebuck (1995) emphasizes that the careful definitions of the camera position and orientation are required as well as measurement scales, grids, or markers in 3D space placed around the subject.

Body scanning can provide hundreds of thousands of measurements of the human body in a very short time according to Cyberware scanners (2006). With a person standing on the scanner's platform, the scanning instruments start at the person's head and move down to scan the entire body. The scan heads collect high-speed 3D measurements every 2 mm to create an accurate 3D data set. The scanner's rapid acquisition speed freezes motion and makes it easy to scan many subjects or to capture different poses appropriate to the application at hand.
2.4.3 Percentile

To describe the size and composition of computer manikins the concept of percentiles is frequently used. Högberg (2005) describes percentiles as the probability distribution data for certain body dimensions within a certain population and not representing actual persons. Commonly used percentiles are the 50th percentile which means that the manikin is in the middle of the spectra of for instance height. A manikin in the 95th percentile of height is taller than 95% of the population, Sjöberg and Sundin (2004). Percentiles are not addable; adding the 95th percentile values for measurements that correspond to the stature produce a taller manikin than that of the 95th percentile manikin.

2.4.4 Pattern of movement

Pattern of movement includes gait and posture, and distinguishes one person from another. This can be used for biometric identification. Green and Huang (2004) means that biometric authentication depends on a significant measurable diversity of a particular physical characteristic, such as iris, fingerprint, signature or gait. Movement patterns vary from person to person and are affected by factors like age, body composition, injuries and previous experiences.
3 Methodology

The methods used for producing the results in this project will be presented below. The purpose is to describe which steps have been taken to reach the results.

3.1 Information retrieval

Sources used for information gathering were foremost the Internet and literature on related subjects. Searches on the Internet were performed in the areas of anthropometry, Motion Capture, ergonomics and for work earlier done on the subject. The Internet was utilized throughout the project. Literature was studied and the interesting findings were discussed and written down in the report. Conference proceedings from DHMC-Digital Human Modeling for Design and Engineering (1998-2006) were also studied and relevant papers were read more carefully and notes taken. Discussions with reference groups gave suggestions for new areas to investigate.

3.2 Brainstorming

On the Internet page Brainstorming (2006) brainstorming is described as a method used for generating ideas in a free thinking environment. The session helps the participants to break free from normal ways of thinking and produce drastic new ideas. There are four corner stones in Brainstorming:

1. **No criticism of ideas**
   
   No judgmental discussing of the ideas during the brainstorming session.

2. **Go for large quantities of ideas**
   
   Quantity is better than quality at this point. Narrowing down can take place later on. If the number of ideas is large the chance of finding a really good one increases.

3. **Combine ideas**
   
   Use other peoples ideas as inspiration for your own.

4. **Encourage wild and unusual ideas**
   
   It is much easier to tame a wild idea then it is to think of an immediately valid one. An idea that seems to be crazy can generate other ideas that are useful.

One way to execute brainstorming is to gather a group, 4 – 20 people, in a room. The group will have a central person that coordinates the proceedings, outlines the rules and assures that the topic is kept. A secretary or a dedicated writer records the ideas on a flipchart or whiteboard for later evaluation.

During this project, brainstorming was used for developing a good test group, finding suitable tasks for motion capturing and determining how/what to measure on the test group.

3.3 Anthropometric measures and techniques

The decision about which measurements were needed for this project was based on the variables possible to change in eM-RAMSIS. They were body height, torso circumference and sitting height, see Figure 2 for visual explanation of body and sitting height. In eM-RAMSIS the sitting height has the denomination *Proportion*. However, in further discussions in this paper sitting height will be used. Additional measures, taken for reference, were arm and hand length and shoulder breadth. Arm length, and shoulder breadth have impact on a persons range of motion, for example how much she or he has to bend the back to be able to reach a specific point in space. The accuracy of the measurements in this project is that of engineering purposes and a tape measure was considered to be sufficient, see further information in chapter 2.4.2 Measurement techniques.
3.4 Tools
Different aids have been used in the various stages of the project. The tools used in the anthropometric measurements, which software has been utilized and how to use the Motion Capture system will be presented below.

3.4.1 Measurement tools
Tools used for measurement were a wall mounted stick with a sliding rod for measurement of body height. The same stick was used for measuring the sitting height when the object was sitting on a table. A tape measure was used for the waist circumference, shoulder breadth and the arm and hand length.

3.4.2 Software
Different software were used during the tests, analysis period and the period of thesis writing. These were:

- EVaRT from Motion Analysis for working with Motion Capture.
- eM-RAMSIS from Tecnomatix, UGS, for manipulating manikins in the analysis phase.
- Process simulate from Tecnomatix, UGS, for visualization of motions recorded with Motion Capture.
3.4.3 Motion Capture

Motion Capture was used during the whole project and the equipment consists of 10 Eagle and Hawk digital cameras connected to two personal computers, one for the EVaRT and one for Process Simulate. In the basic setup the cameras were positioned in a ring around the capture volume as seen in Figure 3.

![Figure 3: Basic camera set up in EVaRT. The inner square is the capture volume.](image)

Before the data recording start, a calibration of the system was required. This procedure was crucial for locating the exact position of the cameras and for accounting of any geometric distortion the camera lenses may have, as well as accurate measuring the camera lens focal length. An L-shaped rod with four markers, Figure 4, was placed on the floor in the middle of the capture volume. The operator made sure all cameras see four markers, if not the cameras or the props were moved until four markers are visible to all cameras. The scene was recorded and the L-shape was removed and the wand collected. The wand was a T-shaped stick and had three markers on the top or the T, see Figure 4, the two on each end exactly 500mm apart. While the cameras recorded, an operator waved the wand around in the capture volume for 20 seconds. The software then begun to calculate the distance between the two outmost markers of the wand. When it arrived at 500 mm the calibration was complete.
When the calibration was finished, the test object was dressed in a special suit and reflectors were placed on given positions on the body. The subject was asked to adopt the T-pose, see Figure 5, and a recording was done. The reflectors could now be seen in the software as dots, hereafter called markers. These were identified by the operator and this identification served as the base for further identification of the human as a template was created. A range of motion was then performed to help the system predict the motion of the markers; this facilitates the identification of markers in movement. The range of motion data often needed editing, i.e., manual identification of markers in some sequences. The template was then extended with the data from the range of motion. This completed the preface and the system was ready for motion capturing.
Methodology

The reflector is a small reflective sphere mounted on a small circular plastic disc, see Figure 6 below. The position of the reflector, usually on an anthropometric landmark is called the reflector position. The list the software which contains the reflector positions in of the included reflectors is called the markerset.

Figure 6: Three reflectors with different dimensions.

3.4.4 Props

During the Motion Capture session props were used as help for the test object. Since the system used was optic, it was important to find suitable props not obstructing the view for the cameras. A frame of a table was frequently used along with a chair. A stick (146 cm long), a stripe, a pallet board, a box and a screw clamp completed the scene. The scene setup with all props present can be seen in Figure 7.

Figure 7: Props and setup for the main test Motion Capture sessions.
4 Design of experiment

To fulfill the purpose and project goal, the experiments were designed. The reasoning behind the design of the different experiments is presented below. To create ideas and a large number of different approaches brainstorming was used in the early stages of the project.

4.1 Evaluation of markerset

During discussions with the reference group, the need to investigate the validity of the markerset used arose. For comparison three different markerset were chosen, one with 30 markers, which is the amount of markers that is needed in eM-RAMSIS; one with 34 markers which is the markerset that Tecnomatix recommend in Human VR User Guide (2006), and finally the markerset that simulation engineers at Volvo Cars Corporation have developed with 42 markers.

The positions of the 30 markers are the same as eM-RAMSIS’s body points, four markers on the head, one on each shoulder, one on each elbow and three on each hand. The pelvis is marked with four markers, there are one on each knee and five on each foot. This can be seen in Figure 8. The two other marker compositions are based on the 30 markerset with additional markers for easier identification in EVaRT. In the markerset recommended by Tecnomatix clavicle, neck base and thigh markers are added, these are marked with red text. Adding head, back, upper- and lower arm and hand offset markers creates the markerset with 42 markers. These added markers are marked with green text. For a more detailed description of each markerset, see Appendix 1.

Figure 8: Front view of the markerset with 30, 34 and 42 markers, respectively.
To be able to validate the markerset a range of motion was designed. The motions were based on early observations of both the eM-RAMSIS manikin in interaction with Motion Capture and EVaRTs recognition of markers. The motions finally consisted of bending over and reaching followed by twisting to reach something high behind and low behind the object.

4.2 Basic Test

Before designing the main test a smaller and more basic test was created. The purpose of the basic test was to get a clearer picture of which movements generated difficulties and strange behavior from the manikin.

Since eM-RAMSIS manikin is very stable in the lower body, an effect of the feet being attached to the floor, no special movements of the legs were included. The upper body was less stable and of greater interest to VCC's ergonomic simulations. EVaRT also exhibits problems with swapping markers mainly from the hip and up. This led to the decision to focus on the movements of the upper body. The series of movements was decided to contain everyday movements such as sitting on a chair and walking around. It should also contain extreme postures such as reaching and bending the back, reaching to the side, squatting, and bending and twisting the back. For efficiency whole the series of poses were captured only with two test objects.

To determine the influence of the anthropometry two different manikins were used; one with the correct length of the test object and the other settings on normal and one with all settings taken from the test object. No normal manikin was used since Chiang (2006) emphasizes the importance of using a manikin which resembles the test object as closely as possible to get valid results from the analysis.

4.3 Main Test

Based on the experience from the basic test and discussions with simulation engineers the main test was designed. Some tasks were also designed to be carried out as desktop simulation. The reason for that was to compare Motion Capture results with desktop simulation results to validate the position of the manikin in relation to the environment. The main test consisted of twisting and bending the upper body, bending and stretching the back, placing a box under a chair, sitting on a chair and finally general movements. General movements were: head facing left, right, up and down; reaching with both hands above the head as far as possible; squatting and at last kneeling with one knee at the time.

For the main test a group with different anthropometry was gathered. To monitor how far the test objects were able to reach a tape measure was attached on the props used for the reaching task.
5 Experiment
The experiments carried out during the course of the project are described in detail in this chapter. First the test for evaluating the markerset is described followed by the basic test that was carried out to get some preliminary results of how eM-RAMSIS responded to different tasks. Taking the experiences from that test the main test was created and carried out by a test group. In Basic and Main test should the manikins created in eM-RAMSIS be compared with the manikins created in Human Builder. This software was however not made available during the course of this project and therefore was the only option to analyze the eM-RAMSIS manikins and see how well they were agreeing with the reality, the test objects.

5.1 Evaluation of markerset
The three different markersets were created in EVaRT and the test object was dressed with the corresponding markerset. The test person then performed a predetermined series of motions for each markerset, as described in 4.1 Evaluation of markerset. To complement the captured sequence photos and video footage was taken. The data was edited and applied to a 50th percentile female manikin.

5.2 Basic Test
The test objects were dressed up with markers and asked to do a series of movements. The series of movements were: sitting on a chair, reaching and bending the back, reaching to the side, squatting, walking around and bending and twisting the back as described in chapter 4.2 Basic test. A chair without back support was used to sit on and it could be raised or lowered to suit the test subject. The different manikins were created using values obtained from the test objects using a tape measure and a wall mounted stick.

5.3 Main Test
The main test consisted of four tasks as described below and was carried out by a test group of eleven people. The manikins used was created using measurements from the test objects.

5.3.1 Test group
Test objects with different anthropometry were contacted and asked to participate in the test; most of them worked at Volvo Car Corporation and were colleagues or acquaintances. The test group consisted of eleven objects, six female and five male, and covered the length span from the 5th percentile female to the 95th percentile male. The group included a corpulent female but failed to include a corpulent male object since no one wanted to participate.

Upon arrival to the lab the test person was told what the test would look like and was asked to put on the suit. Marker positions were adjusted and the test object was measured and the values were taken down in a spreadsheet, see Table 1. The measurements that were collected were: body length, sitting height and waist circumference, which were the measurements possible to adjust in eM-RAMSIS. In addition to that, hand and arm length and shoulder breadth were collected as a complement as these were considered to be critical in some motions, see chapter 3.3 Anthropometric measures and techniques.
Table 1a. Measurements of the male test objects.

<table>
<thead>
<tr>
<th>Measurement [mm]</th>
<th>Length</th>
<th>Sitting height</th>
<th>Waist circumference</th>
<th>Arm length</th>
<th>Shoulder breadth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test object</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>m.a (male a)</td>
<td>1710</td>
<td>870</td>
<td>950</td>
<td>725</td>
<td>400</td>
</tr>
<tr>
<td>m.b</td>
<td>1720</td>
<td>900</td>
<td>900</td>
<td>730</td>
<td>390</td>
</tr>
<tr>
<td>m.c</td>
<td>1740</td>
<td>910</td>
<td>1015</td>
<td>780</td>
<td>410</td>
</tr>
<tr>
<td>m.d</td>
<td>1815</td>
<td>930</td>
<td>1060</td>
<td>795</td>
<td>440</td>
</tr>
<tr>
<td>m.e</td>
<td>2000</td>
<td>1040</td>
<td>820</td>
<td>880</td>
<td>450</td>
</tr>
</tbody>
</table>

Table 1b. Measurements of the female test objects.

<table>
<thead>
<tr>
<th>Measurement [mm]</th>
<th>Length</th>
<th>Sitting height</th>
<th>Waist circumference</th>
<th>Arm length</th>
<th>Shoulder breadth</th>
</tr>
</thead>
<tbody>
<tr>
<td>f.a (female a)</td>
<td>1550</td>
<td>840</td>
<td>740</td>
<td>680</td>
<td>380</td>
</tr>
<tr>
<td>f.b</td>
<td>1710</td>
<td>910</td>
<td>750</td>
<td>715</td>
<td>400</td>
</tr>
<tr>
<td>f.c</td>
<td>1710</td>
<td>1010</td>
<td>1050</td>
<td>815</td>
<td>390</td>
</tr>
<tr>
<td>f.d</td>
<td>1720</td>
<td>900</td>
<td>725</td>
<td>750</td>
<td>370</td>
</tr>
<tr>
<td>f.e</td>
<td>1720</td>
<td>925</td>
<td>970</td>
<td>767</td>
<td>400</td>
</tr>
<tr>
<td>f.f</td>
<td>1815</td>
<td>950</td>
<td>700</td>
<td>810</td>
<td>400</td>
</tr>
</tbody>
</table>

The spreadsheet that was used for anthropometric values also contained a section with lines for the different files that were created under the Motion Capture sequence, see Appendix 2. One of the thesis workers was the test leader while the other handled the computer. The test leader guided the test object through the t-pose and range of motion and then explained which postures would make up the real test, while the computer handler edited the data and created a template.

Task 1 – Twisting and bending the upper body

The test object was told where to stand and to push a strap as far away as possible and then reach toward it with the right hand. They were also asked to adopt the t-pose before and after the task. The computer operator worked the Motion Capture system and the test leader took photos of the test object when being in the most twisted position. Props used for this task was the frame of a table, a stick (146 cm), a stripe and a screw clamp, see Figure 9.
Task 2 – Bending and stretching the back

The test leader showed the object where to stand and to use one hand for support while reaching forward with the other hand. While the subject was in the most stretched position he or she marked the distance with a pen on a measure scale taped on the table frame. Photos were taken and the computer operator asked where the supporting hand was placed. After the Motion Capture sequence was finished the position of the pen-mark was noted and added to the spread sheet. The table frame, a pen and a loading pallet was used as props for this task, see Figure 10.

Figure 9: Task 1- Twisting and bending the upper body.

Figure 10: Task 2- Bending and stretching the back
Task 3 – General movements

The test leader guided the test subject through the general movements and was positioned so that the subject could see the test leader without turning the head too much. They started with rolling the head, followed by rolling the hips, after that kicking the legs forward and backwards. The next position was to reach with the hands above the head, followed by reaching as far forward as possible upwards, and after that squatting and lastly getting down first on one knee and then on the other, see Figure 11.

Figure 11: Task 3 – General movements

Task 4 – Picking up box and sitting on chair

Starting with the t-pose the test object walked up to a small cardboard box on the floor and picked it up. The test leader took a photograph from the side. Then the object walked over to a chair placed in the rear of the capture volume and placed the box under it, aligning the box with the rear legs of the chair. The test leader took a photograph from the side. The object then sat on the chair and then returned to the t-pose, see Figure 12.

Figure 12: Task 4 – Picking up box and placing it under chair, followed by sitting on chair.
6 Analysis

The tests were followed by editing of the data followed by analysis performed in group consisting of the thesis writers and their supervisors.

6.1 Markerset

The tests were followed by analysis focused on the amount of editing of data required and the quality of movement. In general more editing was required with data captured with a markerset consisting of few markers. Similar for all markerset were a difficulty in identifying hand markers during twisting of the back. A better template would probably lead to less mixture of hands and better overall identification. This shows the importance of doing a relevant range of motion and creating a good template.

When using the markerset consisting of 30 markers the EVaRT system had greater difficulty identifying which marker was which. This led to more time consuming manual identification of the markers. Another observation was that left and right shoulders were switched. This phenomenon could probably be explained both by insufficient templates and an inadequate amount of markers to relate to. The shoulder markers were not mixed in the markerset of 34 and 42, almost certainly because of the added markers on the clavicle and neck base. Markers in EVaRT swap if the markers on the test object are positioned to close to each other. When possible, offset markers should be placed asymmetrically on the right and left side of the body.

eM-RAMSIS' head was turned slightly upwards when the test object was looking straight forward since the human head markers did not have the same position as the corresponding body points on eM-RAMSIS' head. eM-RAMSIS' body points had an editing and moving function and this was attempted without success. The head markers on the human could in theory easily be moved to better fit eM-RAMSIS' skin points. Another problem arose when the manikin had broader shoulders than the test object and resulted in a manikin with the shoulders drawn together and up. The solution to this problem has not yet been found.

6.2 Basic Test

The results from using a manikin with correct height displayed a sway-backed manikin when bending over forwards. This phenomenon could probably be explained by the fact that eM-RAMSIS has a longer back than the test object. To fit the manikins back between the rear pelvis markers, also known as Psis markers, and the shoulder markers the back has to be bent. Using a manikin with the correct measurements showed a good resemblance for most postures, however in some postures the appearance of the manikin differed from the test objects, in particular the shoulders and head showed different results.

When sitting on a chair the manikin showed good resemblance, there was no problem with too many markers being hidden. Reaching and bending the back, reaching to the side and twisting of the back showed that the manikin had some difficulty to adopt the pose. The arch of the back and the placement of the shoulders were the things that differed most. No problems were observed that could be related to difference in arm length between the test object and the manikin. That could be explained by the stretch of the arms not being maximal or that the test object's arms were of the same length as the manikin's or close to it. The manikin handled the squatting posture surprisingly well. Walking around showed very good resemblance and since the simulation engineer's only use static postures for their analysis this did not need further investigation. Since the test objects were of approximately the same size there was a need for further investigation of all the tasks except walking around, using test objects of different anthropometry. For detailed pictures see Appendix 3.
6.3 Main Test

General observations concerning the behavior of the manikin will be presented in the following text. This segment will be followed by deeper analysis of the identified problem areas.

Firstly, there were no clear indications that a special anthropometric group showed similar dissimilarities between the test object and the manikin. Dissimilarities occurred for all test objects. Most problems found were related to the back, head and hands. The legs and feet were handled well by the manikin. Where strange positions occurred it could often be ascribed to the absence of crucial markers. The reaching task showed manikins that were hunched, sway-backed or too upright. Squatting and kneeling caused problems for the manikin mainly when knee and foot markers were missing, and the pelvis was often rotated giving the manikin a slight hunch or causing the upper body to lean forward. Another effect observed was that the bending of the knees on the manikin was lesser than that of the test subject. This could possibly be explained by the displacement of the rear pelvis markers, as in picture X. The difference in appearance could also be an effect of the different physical presentation of the manikin. Circumference was the only measure that had an influence on the manikin’s ‘body mass’ which made it impossible to create a manikin that had the same appearance as the test object. People with the same circumference can have completely different body types. One can have a generous lower body and the other a more heavy upper body but they are both generating the same manikin appearance. The thighs of the manikins were almost constantly thinner than the test objects and a lot of the manikins had body fat placed in the wrong positions. These effects do not have an impact on the ergonomic analysis. However, if a picture of a manikin and the test object are presented to a novice in the simulation area these effects may cause misunderstandings. A general observation for the sitting posture was that the back of all manikins were crooked. Manikin hands often adopted strange positions despite many markers. For a compilation of the taken pictures of manikins, test objects and thread models see Appendix 4.

6.3.1 Back and shoulder problems

Kneeling on one knee produced manikins where a majority had a forward rotated pelvis and a back that was also bent over forwards. In some cases the upper body was also twisted, hunched, sway-backed and had displaced shoulders. When lifting the arms above the head, eM-RAMSIS had trouble getting the shoulders into a natural position, especially when the subject lifted the arms outwards and up. If the subject on the other hand lifted the hands forwards and up so that the palms were facing forwards in the end position the result was much better. Squatting and picking up the box presented a situation where many markers were hidden, both by props and by the test objects’ own body. Despite this, the manikin presented a good posture considering the lack of data. When the shoulder markers were hidden the manikin showed slanting shoulders. A problem for all manikins when squatting was the rotation of the pelvis causing a hunched manikin posture.

A general observation for all subjects was that the back of the manikin looked crooked when seated. The rotated pelvis was visible here as well and produced a slightly leaned back posture, sometimes with a grave hunch in the upper back, which made the manikin look as though the chest was sunken in. When bending over, the manikin often bent more at the hip, kept the back flatter and bent the knees on some occasions, whereas the test objects showed a lesser bending at the hip but greater bending of both the upper and lower back combined with moving the shoulder up towards the ear to achieve a maximum reach. The displacement of the rear pelvis markers made the manikin extremely sway-backed since the distance between the pelvis reflectors and shoulder markers decrease, see Figure 13.

Figure 13: The effect of the rear pelvis markers (Psis) being displaced.
6.3.2 Head problems

Since the Motion Capture suit was not delivered until the test series was almost finished, a tight ski costume with a Velcro headband was used instead. Even though the headband was placed as accurately as possible on each test object the head placement of the manikin often differed from the real head position. What appear to be identical head positions produce different manikin head positions. As seen in Figure 14 the thread models gaze slightly upwards and the manikin are generating two totally different head positions. The head position may be influenced by the back position. This behavior can be explained by the fact that eM-RAMSIS’ body points are located on different positions compared to the markers from EVaRT. However, a test where the headband was placed on different positions showed no improvement. The special Velcro suit arrived in time to be used on three objects and the included cap with sowed on Velcro patches produced a manikin with correct head positions.

![Figure 14](image)

*Figure 14: Even though the thread models have basically same head position the manikins have very different head positions.*

6.3.3 Hand problems

Throughout the different tasks the manikin hands were sometimes twisted into positions which did not at all resemble the hand position of the test subject. This occurred both when the hands had all the markers but also when hand markers were missing. Correct positions were generated both with a complete set of hand markers and with so few as one marker. This is illustrated in Figure 15 a-d below. The positions might be influenced by the position and twisting of the rest of the arm. When there were markers missing on the hand and arms the inverse kinematics was most helpful in producing a similar position, but when all markers were present there seemed to be a conflict between the two guidance systems. The position of the hands does not make a position ergonomic or non-ergonomic but contributes considerably to the overall impression of the posture of the manikin, especially when showed to laymen. The grip will have to be adjusted for an ever more convincing manikin. Today the Motion Capture system can not control the hand arrangement.
6.3.4 Reach problems

In bending and stretching the back, the distance from the edge of the table frame to the mark for each test objects maximum reach was measured. The purpose was to compare that distance with one measured with a manikin in a virtual environment. A virtual table of the same size as the table frame used during the tests was created and the manikin was placed in front of it. Photos and video from the test sessions were used as a reference for creating the virtual environment. When the manikin was bending over the table, measurements were taken for both the reaching hand and supporting hand, see Figure 16.
Figure 16: The manikin, the table and the measured distance from the edge of the table to the hand.

A comparison of the measurements showed that the result of the reaching hand differed more than for the supporting hand, as seen in Diagram 1. More detailed data can be found in Appendix 5. The placement of the supporting hand of the manikin corresponded relatively well to the test object. This might be an effect of this arm not being stretched out to maximum.
Diagram 1: A comparison of the reach distance of the test object and their corresponding manikin and the placement of the supporting hand.

The position of the reaching hand of the manikin differs greatly from the test object. A first thought was that the manikin had shorter arms than the test object. However, a comparison showed that the relation between the object and the manikin was the opposite; the manikins had longer arms than the test objects, see Table 2.
Analysis

**Table 2: Comparison between the arm length of the test object and the manikin.**

<table>
<thead>
<tr>
<th>Test object</th>
<th>Arm length, test object [mm]</th>
<th>Arm length, manikin [mm]</th>
<th>Difference [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>f.a</td>
<td>680</td>
<td>691</td>
<td>-11</td>
</tr>
<tr>
<td>f.b</td>
<td>715</td>
<td>759.1</td>
<td>-44.1</td>
</tr>
<tr>
<td>f.c</td>
<td>815</td>
<td>750.2</td>
<td>64.8</td>
</tr>
<tr>
<td>f.d</td>
<td>750</td>
<td>770.4</td>
<td>-20.4</td>
</tr>
<tr>
<td>f.e</td>
<td>730</td>
<td>767</td>
<td>-37</td>
</tr>
<tr>
<td>f.f</td>
<td>810</td>
<td>829.6</td>
<td>-19.6</td>
</tr>
<tr>
<td>m.a</td>
<td>725</td>
<td>805</td>
<td>-80</td>
</tr>
<tr>
<td>m.b</td>
<td>730</td>
<td>795.5</td>
<td>-65.5</td>
</tr>
<tr>
<td>m.c</td>
<td>780</td>
<td>803.8</td>
<td>-23.8</td>
</tr>
<tr>
<td>m.d</td>
<td>795</td>
<td>849</td>
<td>-54</td>
</tr>
<tr>
<td>m.e</td>
<td>880</td>
<td>876.6</td>
<td>3.4</td>
</tr>
</tbody>
</table>

The result presented in Diagram 1 might contain some sources of error such as measurement errors during the test and virtual measuring and incorrect placement of the manikin in relation to the table. Nevertheless, these errors could not account for the large diversity in distance shown above. eM-RAMSIS has difficulties in adopting a posture with extremely stretched arms. The area around the shoulders appeared strange both in this particular test and in the test where the arms were stretched toward the ceiling and this could have an impact on how far the manikin could reach. Being unable to draw any conclusions from the results the need for a further test was identified. A test was designed and the results can be found in chapter 7 *Supplementary reach and bending test.*
Evaluation of the manikin building function in eM-RAMSIS when using Motion Capture
7 Supplementary reach and bending test
Since the main test with the reach and bending task showed inadequate results a more detailed test was required with a more restrained method. This test is presented below.

7.1 Design
The problem with the main test was the many variables and it was therefore impossible to determine the cause of the strange behavior of the manikin.

One of these variables was the placement of the manikin in the virtual world; the main test had no restrictions in the foot placement except that the toes were not allowed inside the table frame. To solve this problem two feet were drawn on the floor for the test objects to place their feet on and their position was carefully measured see Figure 17. This position could then be used for placing of the manikin in relation to the table in the virtual world. The sole of the foot had to completely touch the floor during the whole capture.

Another problem was the thighs of the manikin and how much penetration of the table edge to allow. To facilitate the analysis of the new manikin postures, measurements would be taken of the test objects thighs on the height where the edge of the table touched the thigh. Circumference, breadth and depth of the thigh as well as the height would be measured.

A more well-defined end position of the reaching hand was desired so instead of marking it with a pen as in the main test a different approach was introduced. The test object would push a stripe along a piece of string attached to the table frame. This meant that the exact position of the fingertip would be known since the string was fixed in all dimensions. Moreover, the fingertip was an easily identifiable part of the manikin geometry. All test objects would use the same hand, and it was decided to be the right one since it would provide a good view for the video camera used. The placement of the supporting hand was of no interest in the supplementary test.

![Figure 17: Placement of the feet during the test.](image)
7.2 Experiment

The test group consisted of four test objects, two male and two female and all had participated in the main test. The test was performed using the frame of the table, a piece of cord and a stripe. The test objects’ feet were carefully placed on the pre decided spots. When correctly placed they adopted the t-pose and then bent over and pushed the stripe as far along the stripe as they could without any part of the sole of the feet ever leaving the floor. A piece of tape was attached on the objects’ thigh on the point where the edge of the table touched the thigh.

7.3 Analysis

The manikins corresponding test object m.a, m.c, f.b and f.d were applied to the recorded data. The manikins were placed in front of the virtual table on the given foot position as explained in chapter 7.1, measurements were taken and are presented in Table 3. A compilation of the taken pictures of manikins, test objects and thread models can be found in Appendix 6.

Table 3a: Measurements of the test objects

<table>
<thead>
<tr>
<th>Test object</th>
<th>Thigh breadth/depth/height from floor [mm]</th>
<th>Placement of reaching hand: lengthwise/from side of table [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>f.b</td>
<td>175/180/770</td>
<td>1200/265</td>
</tr>
<tr>
<td>f.d</td>
<td>160/160/750</td>
<td>1220/265</td>
</tr>
<tr>
<td>m.a</td>
<td>150/150/740</td>
<td>1220/265</td>
</tr>
<tr>
<td>m.c</td>
<td>160/180/770</td>
<td>1220/265</td>
</tr>
</tbody>
</table>

Table 3b: Measurements of the manikin in the virtual environment

<table>
<thead>
<tr>
<th>Manikin</th>
<th>Thigh breadth/depth/height from floor [mm]</th>
<th>Placement of reaching hand: lengthwise/from side of table [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>f.b</td>
<td>155/160/777</td>
<td>1011/288</td>
</tr>
<tr>
<td>f.d</td>
<td>146/158/749</td>
<td>1116/38</td>
</tr>
<tr>
<td>m.a</td>
<td>148/151/740</td>
<td>1132/88</td>
</tr>
<tr>
<td>m.c</td>
<td>167/168/773</td>
<td>1098/108</td>
</tr>
</tbody>
</table>

Table 3c: The difference between the test object and the manikin

<table>
<thead>
<tr>
<th>Test object/Manikin</th>
<th>Thigh breadth/depth/height from floor [mm]</th>
<th>Placement of reaching hand: lengthwise/from side of table [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>f.b</td>
<td>20/20/-7</td>
<td>189 / -23</td>
</tr>
<tr>
<td>f.d</td>
<td>14/2/1</td>
<td>104 / 227</td>
</tr>
<tr>
<td>m.a</td>
<td>2/-1/0</td>
<td>88 / 177</td>
</tr>
<tr>
<td>m.c</td>
<td>-7/12/-3</td>
<td>122 / 157</td>
</tr>
</tbody>
</table>

As in the main test all manikins showed reaching problems and reached between 88 mm to 189 mm shorter than the test objects. When the manikins were placed at a given position a problem appeared, some of them adopted a position that resembled the position of the test object very well and some did not. As seen in Table 3 the placement of the reaching hand differs greatly in the measurement from the side of the table for three out of four manikins.
Supplementary reach and bending test

In the test the left hand was placed on the left side of the table frame for support and the right hand on the cord 265 mm from the right side of the table frame. The difference in resulting position can be seen in Figure 17a and 17b, were both manikins had the same foot placement but 17a adopt a incorrect position.

*Figure 17a: Correct placement of the feet and incorrect placement of the upper body.*

*Figure 17b: Correct placement of both feet and upper body.*

This phenomenon was perplexing. However, it was not a part of the main purpose of this thesis project and was therefore left for further investigation and discussion at Volvo Cars.

The thickness of the thighs did not differ much between the test object and the manikin. As seen in Figure 18 the thigh of the manikin penetrated the table approximately as far as the thighs of the test object did. This could be interpreted as a further evidence of the foot positioning being correct and that the method used produced valid results. In short: that the manikin was correctly positioned against the table and that the shortcomings of reaching originated from something else. Using this method with fixed foot positions solved the problems encountered in the main test with knowing where the test object stood and deciding how to position the manikin with regard to the thighs and the table edge.
Figure 18a: The thighs of Male a pressed into the table.

Figure 18b: The thighs of Male c pressed into the table.
Supplementary reach and bending test

Figure 18c: The thighs of Female b pressed into the table.

Figure 18d: The thighs of Female d pressed into the table.
Evaluation of the manikin building function in eM-RAMSIS when using Motion Capture
8  Approach for producing a more valid manikin posture

There are different approaches for creating a more valid manikin. This chapter will cover some of the most useful methods.

8.1 Reflectors and costume

The placement of the reflectors on the test object corresponds to the markerset loaded into EVaRT. The actual positions on the human body, i.e. landmarks, should be followed as closely as possible but the system is rather flexible and gives good results with different reflector positions. Nevertheless, it is very important that the reflector placement has the right height, especially for the Psis markers. These reflectors together with the reflectors on the object shoulders represent the test objects back length. The back of the manikin will become sway-backed if this length does not correspond to the manikin back length, see Figure 19.

Figure 19: Incorrect placement of the Psis reflector leading to a faulty manikin posture.

The Motion Capture costume is a two piece suit, consisting of jacket and pants. If the jacket is not connected to the pants it will slide up during some motions and therefore generate a false manikin posture. This can easily be avoided with some pieces of Velcro that connect the jacket with the pants.
8.2 Unmarking markers

The inverse kinematics is of large significance in eM-RAMSIS’ motions and when the manikin also gets information from EVaRT on how to position the body parts there seem to be a conflict. This is probably a result of too much information to the manikin. A quick way to solve the problem is to unmark some of the markers in the area that appears odd, see Figure 20. For more examples see Appendix 7. Unmarking can also be applied when reflectors on the test object has an incorrect position, for example if the jacket has ridden up in the back. Which marker that needs to be unmarked differ from case to case and it is therefore best to try different combinations for the specific case and compare the result with the video or photo.

![Figure 20](image)

*Figure 20: Unmarking markers for a better appearance.*

8.3 Desktop simulation / Manual manipulation

The Motion Capture device at VCC has no virtual gloves and is therefore not able to generate information of the hand appearance, e.g., if the hand is open or formed to a fist. As a result of that, it is necessary to adjust the hands manually. A manual manipulation of the head position and feet may also be required.

8.4 Camera settings and view

Sessions with a lot of props or with tasks where the test object has to be inside the props, e.g. a driver seat in a car, can present difficulties for the system to see all reflectors. Every reflector has to be seen by a minimum of three cameras, moving and tilting the cameras is a way of solving this. Placing one or more camera inside the props or lowering some of them to a lower level increases the chances of marker identification. Due to the time limitation of this project further research in this area have not been performed.
8.5 The importance of having a calibrated system

Calibrating the system as closely to the beginning of the session as possible ensures a good Motion Capture result. The cameras can be turned on and left running for a period of time so that they are warmed up before calibrating. This avoids the calibration being faulty due to for instance changes in camera focal lengths due to temperature changes. If the system is not calibrated the cameras appear to be cross eyed and have difficulty in recognizing the markers, this can be ascribed to the fact that each marker has to be seen by at least three cameras. This results in both poor data and a difficulty for EVaRT to identify the markers and creating a thread model. Lack of data may provide too little information for generating a correct manikin position.
Evaluation of the manikin building function in eM-RAMSIS when using Motion Capture
9 Discussion

The purpose of this project was to investigate how well the eM-RAMSIS manikin resembled and acted like a test object when using Motion Capture data to guide it. The project should also answer the question of whether a separate manikin building software was necessary and how to tackle problems encountered when using Motion Capture together with eM-RAMSIS. The work focused on how eM-RAMSIS reacted in different situations and the work with the Motion Capture system has indirectly led to guidelines and a method for handling the software and data. In order to assess how much better results got with a manikin created in the advanced anthropometrics editor Human Builder the plan was to use this software for comparison. The software was not available during the course of the project so this study was not executed, and therefore no recommendations can be made about this software since the effects of using this manikin is unknown. This is still a relevant question to answer so a recommendation will be made to evaluate the manikins of this software.

9.1 Sources of error

Measurements taken of the test subjects may have been incorrect; measurements made with a tape measure tend to be inaccurate. However, the measurements are considered accurate enough for engineering purposes. Tape measure and a measuring stick are easy to handle and are the equipment that will be available for the simulation engineers in the Motion Capture lab. These are considered to be acceptable tools for this type of measuring. Choosing which measurements would be taken was based on the variables in eM-RAMSIS, and then some measurements were added that seemed relevant at the time, such as arm length and shoulder breadth. If evaluation of the manikins created in Human Builder will be done, there is a need of gathering more measurements from the test objects.

Handling of the Motion Capture equipment and other software may have caused problems. Better knowledge of the EVaRT software might have produced better data faster. There may possibly be a function for triangulating the position of hidden markers based on the positions of known markers. Such a function could have lead to a more complete set of data to guide the manikin and perhaps a better posture in some situations. This lack of knowledge will not have influenced the outcome of this project except the time needed for editing data.

The props used consisted mostly of the frame of a table, a chair and a small cardboard box. The table was not fastened in the floor, which meant that it might move if leaning upon it to heavily. This resulted in some of the test objects barely using it for support and resulting in a shorter reach than test objects that leaned on it heavily but carefully. It is an advantage to have as few props as possible since they risk obstructing the camera view so that reflector information is lost. Problems with hidden reflectors occurred despite the few props, different camera view settings might have reduced this problem.

9.2 Test evaluation

The markerset test was focused on the editing of data and the quality of movement. The tasks used showed no problems with the manikin movement but showed that more editing was needed in EVaRT when using a markerset with few markers. Additional advantages with using a markerset with many markers is that the data is still useful when reflectors are hidden by props or the objects own body. What could be observed in the partially static tasks performed in the main test was that the Motion Capture information considering the position of the back of the test object seemed to be inadequate. Adding a marker on the spine could decrease the trouble with sway-backed or hunched manikins.
The basic test was performed to see the difference in behavior between manikins created with different amount of test object measurement data as input. The result was that the manikin should be created using actual measurements for the available variables. This fact is supported by a paper on the subject; see Chiang (2006). In the early observations it was discovered that the manikin handled movements of the legs fairly well and had a great help from the inverse kinematics used by eM-RAMSIS. Therefore it was decided that tasks with special focus on the legs was unnecessary. The tasks performed in the basic test were analyzed and the manikin was considered to take good positions. In retrospect the judgment of postures have become harsher the more postures have been analyzed. If the early postures were reconsidered at the end of the project the opinion would probably be different. However, the decision of excluding tasks focused on the legs was strengthened since the manikin's leg positions were very alike the test object's. Other reasons for getting good results in the basic test were the limited use of props, this resulting in few hidden reflectors and therefore good manikin postures.

Further tests of the placement of head and foot reflectors before the main test was launched would have decreased the effects of faulty marker positions. Since there was supposed to be a way to move the body point on the manikin it did not seem to be a big problem at the time. Further investigation of the exact positions of reflectors on the body before the main test might have produced better manikin postures. Nevertheless the postures resemble the actual posture quite well even though the reflectors were not positioned exactly the same on every test object. This seems to imply flexibility in the manikins following of the markers.

The main test was designed with the intent to get as much information from as few tasks as possible, since most test subjects had to take time from their day jobs to participate. The goal was that each test session should take one hour, and that goal was fulfilled for almost all test objects. The tasks which included sitting, reaching, stretching of arms forward and over the head, twisting of the back, squatting and kneeling gave a good set of data to analyze. However, the photos taken did not always show the angles needed for comparison of the interesting areas of the manikin.

The execution of the test series with the test objects was uniform. One person handled the computer and the other one was test leader, the tasks were carried out in the same order, and the test objects received the same instructions; basically what the task was and they were free to solve the problem however they wanted. In retrospective the foot placing in the reaching task should have been fixed. That would have made the positioning of the manikin easier and more correct when measuring the reach of the manikin in the virtual world.

The test group consisted of eleven men and women and this is too few to get results that are statistically significant, however no faults or effects occurred that could be identified as to occur only for one length, size or gender group. The faults seemed to be more related to the manikin than the test object. The test group consisted of no trained assembly workers but of persons related to this project and of different anthropometric combinations. The lack of assembly workers should not have any impact on the results since the tasks were general and not assembly tasks. One advantage of using people related to the project were that most of them had previous experience from working with Motion Capture and had an understanding of how the results from the study would be used. This made the explanation of the tasks and the workflow easy. They also showed great understanding when there was waiting time while the template was created.

In some postures the manikin exhibited a pattern that seemed to imply that the manikin had built in limitations. Our tallest man was too tall for making manikin his length so his manikin is 50 mm shorter than him. One of our female test objects had a long back and the software could not handle that, making the back of her manikin 30 mm shorter than in reality. For these subjects the results can not be considered to be absolutely correct but the manikins showed no recurrent strange behavior. The manikins corresponding to objects with extremely flexible knees, bordering on overflexible, did not mimic this behavior but bent the knees slightly instead. The task which included raising the hands above the head often resulted in strange positioning of the manikins shoulders. This can be an effect of the manikin having trouble with the Motion Capture interacting with the inverse kinematics or that the shoulder markers are in the wrong position. It could also be a built in reluctance for raising hands above the head and moving the shoulders upwards. When stretching forwards the shoulders did not follow the hands forward, this gave the manikin a less stretched posture than the test object.
Discussion

The supplementary test was performed with a stricter method than the preceding tests. Therefore many of the potential sources of error found in the main test were eliminated. A fixed foot positioning gave the manikin a fixed point in the virtual world to be positioned by, as well as the table which also had a well known size and position. The thickness of the thighs did not differ much between the test object and the manikin. As seen in chapter 7 the thighs of the manikin penetrated the table approximately as far as the thighs of the test object did. This could be interpreted as a further evidence of the foot positioning being correct and that the method used produced valid results. In short: that the manikin was correctly positioned against the table and that the shortcomings of reaching originated from something else. At this point the problems seem to arise from the manikin itself. Then the question has to be what kind of manikin does Human Builder generate? An anthropometrically correct one of course, but is it different from eM-RAMSIS in any other ways? The effects of using an anthropometrically correct manikin has to be investigated but they might even reach shorter than the manikins in this test since they all had arms that were longer than the test objects. An explanation of the strange phenomenon that some of the manikin seemed to have been shifted to one side of the table has not been found.

The analyses have been based mostly on visual comparison between pictures of the test object, taken during the Motion Capture session, and the posture of the manikin in the same frame. The postures are comparable since the video camera was connected to the Motion Capture system via fire wire and the film is connected to the captured data. When editing the data the film shows the same frame as the data. Thus, when connecting the manikin to the data it adopts the pose the test person had in that frame. Since the manikin exists in a 3D world it is important to look at the manikin from the correct view, otherwise the perspective might make the body angles look better or worse than they actually are. Some of the first pictures of manikins taken was from the wrong angle and made evaluation impossible, but these were remade with a better angle. The pictures of the test object, the manikin and the thread model were compiled in a document which was viewed and discussed with the simulation engineers and the thesis instructors. Visual assessment of the manikin posture is the prevailing method used at VCC today. The ergonomist and the manufacturing engineer view the ergonomic report together and judge the working pose. The ergonomic report includes a RULA analysis which was planned to be used in the judgment of the manikin postures from this project. This analysis tool is quite blunt though and would probably not show any difference in the analysis since the categories are wide. Furthermore it might be difficult to compare an analysis result from a computer with an analysis performed by a person.

A big challenge was to decide what defined the manikin as being good enough. It is always hard to state what is good enough and it varies from person to person. However, since this project is purchased by VCC the good enough analysis had to match their philosophy on the subject. As commented above, visual assessment by the ergonomist and manufacturing engineer is the most common method at VCC and was therefore used as a measurement for what was good enough in the analysis of this project. No ergonomist has been involved in the analysis of the pictures from this project though. It was also hard to identify and assess which bad results could have been better if a better manikin was available.

9.3 Manikin limitations

The eM-RAMSIS manikin that has been used during this project has an appearance that often differs from the test subject's appearance. A larger waist circumference resulted in extra body volume being added in an unnatural way. The thighs were more or less constantly thinner than the subjects, which also made it difficult to place the manikin in the right position in the 3D-world for the measuring. The fact that the manikin had a different anthropometric composition than the test object may have caused some misinterpretation of the postures during the analysis.

9.4 Usability

To get valid and usable results from the Motion Capture system the constellation of the group of workers who perform the tasks is crucial. The postures and motions can not be applied to scaled manikins so the actual test persons must cover the span from the 5th percentile female to the 95th percentile male, or represent the population at Volvo Cars.
Each posture is based only on the behavior of one person but should still produce more valid and general results than those generated by desktop simulation. The position represents how at least one person actually moved.

The process of preparing the system for a capture session is time consuming, and the step that takes the most time is the creation of the template. When this is done the process of actually capturing is quick and many tasks can be covered in one session. To be able to use this system as a standardized work method this time would have to be shortened to decrease the waiting time for the test object.

It is still a new technology at Volvo Cars so improvement of the method and handling of the system will happen quickly the more the system is used. One challenge still remaining is to develop a system for choosing which tasks to Capture.

Today (fall 2006) the system is only used for static analyses of work postures. But one of the Motion Capture techniques strongest sides is that it can capture and recreate moving objects, so the system would still be useful if Volvo Cars starts requesting and using dynamic analyzes of the whole mounting sequence.
10 Conclusions
This master’s project has led to the following conclusions.

Use all available anthropometric settings
The tests show that the best result is generated when the manikin settings available are used. Always measure the length, the sitting height and the waist circumference of the test object and create a manikin using these measurements.

Unmark markers to create a more valid posture
If the recorded data generate an odd posture of the manikin, unmarking markers may create a more valid posture. Use the video camera for recording reference footage that can be used during the editing of data and for verifying the manikin posture. Additional data views helps in the evaluation of the manikin posture.

eM-RAMSIS is not as flexible as the human test object
eM-RAMSIS does not have the same flexibility in its upper body as the test object and has therefore shown problems in reaching as far as the test object when bending over forwards.

Relocate the cameras for a better data collection
To ensure a better data collection when using many props a relocation of the Motion Capture cameras may be needed. If the cameras appear cross eyed and can not see all markers, and the markers flicker on the computer screen the system needs to be recalibrated.

The work with Motion Capture system has indirectly led to guidelines and methods for handling the software and data. These guidelines are compiled in Table 4: Troubleshooting.

Table 4: Troubleshooting – Problems and remedies

<table>
<thead>
<tr>
<th>Symptom</th>
<th>Cause</th>
<th>Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>The manikin is sway-backed</td>
<td>The back of the manikin is too long and is bent to be able to fit between the rear pelvis markers and the shoulder markers.</td>
<td>• Check that the manikin has the same measurements as the test object.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Check that the jacket has not ridden up the back, fasten it to the pants with the Velcro strips.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Check that the shoulder markers are in the correct position.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Try unmarking the Psis markers in EVaRT and place the manikin in the standing position and then let the manikin take the position again.</td>
</tr>
<tr>
<td>The manikin is hunched</td>
<td>The distance between the shoulder markers and the pelvis markers does not match the length of the manikin back.</td>
<td>• Check that the manikin has the same measurements as the test object.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Unmark the Asis markers and let the manikin take the posture again starting from the standard standing pose.</td>
</tr>
<tr>
<td>Evaluation of the manikin building function in eM-RAMSIS when using Motion Capture</td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------------------------------------------------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>The shoulders or arms of the manikin looks strange</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Check the position of the shoulder markers.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Unmark the markers of the arm but leave the shoulder and the wrist identified, the inverse kinematics will position the hand and it might look better.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Then try to leave the elbow marked and the shoulder unmarked and observe the result.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Unmark the whole arm except the hand markers and observe the result.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>EVaRT can not see all markers (typically 30 of 42)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Recalibrate the system, without props if there is much in the capture volume.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Make sure the cameras are looking at the interesting area. Try having some cameras at a lower level.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>The manikin can not find the EVaRT markers in Process Simulate</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Disconnect the connection to EVaRT and then reestablish it.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• If the markers do not appear disconnect the link and restart EVaRT. Reestablish the link when EVaRT is restarted.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>The thread model does not appear in EVaRT.</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Try extending the template with additional postures.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Let the test object walk out of the capture volume and in again.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Let the test object stay in the capture volume for a while and the system might recognize the test object.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
11 Recommendations for further work

- Compare the recorded manikin results with manikins made with Human Builder
  This evaluation will answer the question whether a manikin created in Human Builder generates a more accurate result than the manikin used at Volvo Cars today. Use the recorded data with manikins that have been created in Human Builder. However, for this action more measurements need to be collected from the test objects. Since a major part of the test group is located at Volvo Cars, Torslanda, an extended measurement series should not be a problem.

- Evaluate the use of big reflectors
  The Motion Capture equipment contained reflectors of three different sizes, see Figure 6. During the test presented in this thesis only the reflector of medium size was used. There is, however, a possibility that larger reflectors can be spotted more easily by the cameras and therefore generate data containing more markers than data recorded with smaller markers.

- Changing the settings of eM-RAMSIS’ markerset / Evaluate the current 42 markers markerset
  According to the developer at UGS it is possible to change the body points on eM-RAMSIS. This may give the possibility to move the markers on eM-RAMSIS and perhaps generate better marker positions. For example some hand markers may be moved to the back since some problems arose in this area. If this generates better data it is also possible that the markerset consisting of 42 markers could be reduced.

- Evaluate the use of an OH projector during Motion Capture sessions.
  The test object will probably get a better feeling for the task if he/she can see the virtual environment and him-/herself as a manikin on a screen or wall during the Motion Capture session. This will also simplify the positioning of the manikin in the virtual environment.

- Placement of the manikin in the virtual environment
  Evaluate the behavior of the manikin when placing it in the virtual environment. Using more than one fixed point might make the positioning easier especially if adjustments of the position are needed.
Evaluation of the manikin building function in eM-RAMSIS when using Motion Capture
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Human factors and ergonomics society
Santa Monica

Tecnomatix Process Simulate 7.6, Human VR (Virtual Reality) User Guide
Appendix

Appendix 1: Markerset 30, 35, 42
Appendix 2: Test protocol
Appendix 3: Basic test
Appendix 4: Main test
Appendix 5: Test object vs. manikin
Appendix 6: Supplementary reach and bending test
Appendix 7: Unmarked markers
Appendix: Volvo Marker Location Set
The original set was defined for motion capturing with the Jack VR application, version 4.X, and the Motion Analysis motion capturing system. It has then been revised and extended to better fit Volvo needs.
Not all markers are used in the Process Simulate markerset. The ones used in this system as well as in EVaRT are marked with a capital start letter. The other ones are used for the system to distinguish between left and right, or to define a part as rigid (three markers needed). Note that the markers Thigh_R and Thigh_L need to be positioned asymmetrically. (They are used by the system to distinguish between left and right. Their exact position is not critical, but it is essential that they are not positioned symmetrically.)
## Appendix 1 – Definition of the evaluated marker sets, 30 34/35 and 42 markers respectively (2/11)

<table>
<thead>
<tr>
<th>Marker Set</th>
<th>front view</th>
<th>rear view</th>
<th>side view</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head_r</td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Head_l</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acromion_r</td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Acromion_l</td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>mid_clavicle</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elbow_R</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Elbow_L</td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>ASIS_R</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASIS_L</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metacarpal2_side_R</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Metacarpal5_side_R</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Metacarpal2_side_L</td>
<td>x</td>
<td>x</td>
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<td>Metatarsal5_side_L</td>
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<td>Toe_Front_L</td>
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<td>PSIS_R</td>
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</tr>
<tr>
<td>head_Side_Right</td>
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<tr>
<td>backOffset</td>
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<tr>
<td>upperArm_R</td>
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<td>forearm_R</td>
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<tr>
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<td>forearm_L</td>
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<tr>
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</table>
Appendix 1 – Definition of the evaluated markersets, 30 34/35 and 42 markers respectively (3/11).

Markerset with 30 markers – front view
Appendix 1 – Definition of the evaluated markersets, 30, 34/35 and 42 markers respectively (4/11).

Markerset with 30 markers – back view
Appendix 1 – Definition of the evaluated marker sets, 30, 34/35 and 42 markers respectively (5/11).

Markerset with 30 markers – side view
Appendix 1 – Definition of the evaluated marker sets, 30, 34/35, and 42 markers respectively (6/11).

Markerset with 34 markers – front view
Appendix 1 – Definition of the evaluated marker sets, 30, 34/35 and 42 markers respectively (7/11).

Markerset with 34 markers – back view
Appendix 1 – Definition of the evaluated marker sets, 30 34/35 and 42 markers respectively (8/11).

Markerset with 34 markers – side view

Marker subsets:
- Head_rb
- Head_r
- Acromion_r
- clavicle
- backOffset
- neck_Base_Rear
- Elbow_R
- Wrist_Midtop_R
- ASIS_R
- PSIS_R
- Metacarpal2_side_R
- Metacarpal5_side_R
- thigh_R
- Knee_lateral_R
- Ankle_front_R
- Ankle_Back_R
- Toe_Front_R
- Metatarsal5_side_R

Markerset with 34 markers – side view
Appendix 1 – Definition of the evaluated marker sets, 30 34/35 and 42 markers respectively (9/11).

Markerset with 42 markers – front view
Appendix 1 – Definition of the evaluated marker sets, 30 34/35 and 42 markers respectively (10/11).

Markerset with 42 markers – back view
Appendix 1 – Definition of the evaluated markersets, 30 34/35 and 42 markers respectively (11/11).

Markerset with 42 markers – side view
## Appendix 2 – Test protocol

### Test protocol

**Project name:**

---

### Subject

<table>
<thead>
<tr>
<th>Name</th>
<th>Age</th>
<th>Body height</th>
<th>Sitting height</th>
<th>Waist circumference</th>
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<table>
<thead>
<tr>
<th>Arm length</th>
<th>Shoulder breadth</th>
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### T-pose

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<th>Placement of strap</th>
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### Range of motion

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### Twisting and bending of the upper body

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### General motions

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### Bending and stretching of the back

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</tbody>
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<table>
<thead>
<tr>
<th>Placement of right hand</th>
<th>Reach of left hand</th>
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<tbody>
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### Placing box under the chair

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<th>Reach of right hand</th>
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</table>

<table>
<thead>
<tr>
<th>Placement of right hand</th>
<th>Reach of left hand</th>
</tr>
</thead>
<tbody>
<tr>
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</tbody>
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---
Manikin with correct height/ circumference and sitting height
Basic test

Manikin with correct height

Manikin with correct height/circumference and sitting height
Basic test

Manikin with correct height

Manikin with correct height/circumference and sitting height
Basic test

Manikin with correct height

Manikin with correct height/ circumference and sitting height
Manikin with correct height

Manikin with correct height/circumference and sitting height
Basic test

Manikin with correct height

Manikin with correct height/ circumference and sitting height
Twist Male

m.a (male a)

m.b
Twist Male

m.c

m.d
Twist Female

f.a

f.c
Twist Female

Appendix 4 – Main test (5/62)
Twist Female
General Motions Reach - Male

m.a

m.b
General Motions Reach - Male
General Motions Reach - Male
General Motions Reach - Female

f.a  f.c

Appendix 4 – Main test (10/62)
General Motions Reach - Female
General Motions Reach - Female
General Motions Reach - Female
General Motions Squat- Male

m.a

m.b
General Motions Squat - Male
General Motions Squat - Male
General Motions Squat -Female

f.a

f.c
General Motions Squat -Female
General Motions Squat -Female

f.e

f.f

Appendix 4-Main test (1962)
General Motions Kneeling - Male
General Motions Kneeling- Male
General Motions Kneeling- Male
General Motions Kneeling - Male
General Motions Kneeling- Male
General Motions Kneeling - Female

Appendix 4 - Main test (25/62)
General Motions Kneeling - Female

Appendix 4 - Main test
General Motions Kneeling - Female
General Motions Kneeling- Female
General Motions Kneeling - Female
General Motions Kneeling- Female

Appendix 4 - Main test
(30/62)
Box-picking Male

m.a

m.b

Appendix 4 - Main test (31/62)
Box-picking Male
Box-picking Male

m.e
Box-picking Female

No Picture
Box-picking Female
Box-picking Female

Appendix 4 - Main test (36/62)
Box-placing Male

m.a

m.b

Appendix 4 - Main test (37/62)
Box-placing Male

Appendix 4 - Main test (38/62)
Box-placing Male
Box-placing Female

f.a

No Picture

f.c

Appendix 4 - Main test
(40/62)
Box-placing Female

Appendix 4 - Main test (41/62)
Box-placing Female
Box-sitting Male

Appendix 4 - Main test

(43/62)
Box-sitting Male
Box-sitting Male
Box-sitting Female
Box-sitting Female
Box-sitting Female
Box-sitting Female
Box-sitting Female
Reach with right hand - Male

m.a

m.b

Appendix 4 - Main test
(51/62)
Reach with right hand - Male
Reach with right hand - Male
Reach with right hand - Female

f.a

f.c

Appendix 4 - Main test (64/62)
Reach with right hand - Female
Reach with right hand - Female
Reach with left hand - Male

m.a

m.b
Reach with left hand - Male

Appendix 4 - Main test (58/62)
Reach with left hand – Male

m.e
Reach with left hand - Female

f.a

f.c

Appendix 4 - Main test (60/62)
Reach with left hand – Female

Appendix 4 - Main test
Reach with left hand – Female

f.e

f.f

Appendix 4 - Main test (02/62)
### Female measurements [mm]

<table>
<thead>
<tr>
<th>Test object</th>
<th>Length</th>
<th>Sitting height</th>
<th>Waist circumference</th>
<th>Arm length</th>
<th>Shoulder</th>
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<tbody>
<tr>
<td>f.a</td>
<td>1550</td>
<td>840</td>
<td>740</td>
<td>680</td>
<td>380</td>
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<tr>
<td>f.b</td>
<td>1710</td>
<td>910</td>
<td>710</td>
<td>715</td>
<td>400</td>
</tr>
<tr>
<td>f.c</td>
<td>1710</td>
<td>1010</td>
<td>1050</td>
<td>815</td>
<td>390</td>
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<tr>
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<td>725</td>
<td>750</td>
<td>370</td>
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<td>970</td>
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<td>400</td>
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<tr>
<td>f.f</td>
<td>1815</td>
<td>950</td>
<td>700</td>
<td>810</td>
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<table>
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<th>Waist circumference</th>
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<td>970</td>
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<td>f.b</td>
</tr>
<tr>
<td>f.c</td>
</tr>
<tr>
<td>f.d</td>
</tr>
<tr>
<td>f.e</td>
</tr>
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## Appendix 5- Test object vs. manikin (2/3)

### Male measurements [mm]

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<th>Waist circumference</th>
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<td>900</td>
<td>730</td>
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<table>
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<th>Length</th>
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<th>Waist circumference</th>
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<tr>
<td>m.b</td>
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<td>900</td>
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<td>m.b</td>
</tr>
<tr>
<td>m.c</td>
</tr>
<tr>
<td>m.d</td>
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<tr>
<td>m.e</td>
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-80
-65.5
-23.8
-54
3.4
## Appendix 5- Test object vs. manikin (3/3)

### Reach right [mm]

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<th>Reach right manikin</th>
<th>DiffERENCE</th>
<th>Placement left test object</th>
<th>Placement left manikin</th>
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### Reach left [mm]

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<td>960</td>
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<td>800</td>
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<td></td>
<td>460</td>
<td>441</td>
<td>19</td>
</tr>
</tbody>
</table>
Appendix 6 – Supplementary reach and bending test (1/16)
Measured distance: 1220 mm
Difference: ca 87 mm

Measured distance: 265 mm
Difference: ca 177 mm
Appendix 6 - Supplementary reach and bending test (3/16)

Manikin: 151/148 mm
M.a: 150/150 mm
Appendix 6 – Supplementary reach and bending test (4/16)

Thigh thickness on the height were the manikin touch the table.
Male c
Measured distance: 1220 mm
Difference: ca 122 mm

Measured distance: 265 mm
Difference: ca 157 mm
Appendix 6 – Supplementary reach and bending test (7/16)

Manikin: 167/168 mm
M.c: 160/180 mm
Thigh thickness on the height were the manikin touch the table.
Female b

Appendix 6 – Supplementary reach and bending test (9/16)
Measured distance: 1200 mm
Difference: ca 188,5 mm

Measured distance: 265 mm
Difference: -23 mm
Manikin: 160/152 mm
F.b: 175/185 mm

Appendix 6 – Supplementary reach and bending test (11/16)
Thigh thickness on the height were the manikin touch the table

Appendix 6 - Supplementary reach and bending test (12/16)
Female d
Measured distance: 1220 mm
Difference: ca 104 mm

Measured distance: 265 mm
Difference: ca 227 mm
Manikin: 158/146 mm
F.d: 161/161 mm
Thigh thickness on the height were the manikin touch the table.

Appendix 6 - Supplementary reach and bending test (16/16)
Reaching

a: All markers
b: Acromion and arm unmarked
Squating

a. All markers
b. Asis unmarked

a: All markers
b: Asis unmarked

Appendix 7 – Unmarked markers (26)
Reaching

a: All markers
b: Asis unmarked

Appendix 7 – Unmarked markers (3/6)
Sitting

Appendix 7 – Unmarked markers (4/6)

a: All markers
b: Asis unmarked
Twist

Appendix 7 – Unmarked markers (5/6)

a: All markers
b: Asis unmarked
Marker positions on the body with the new suit

The jacket and pants need to be merging, preferably with Velcro so the dress up will go smoothly.