Bachelor Degree Project

UNIVERSITY
OF SKÖVDE

SIMULATION AND EVALUATION OF WORK CONDITIONS OF HEALTHCARE PERSONNEL USING DHM TOOLS AND MOTION CAPTURE SYSTEMS

Bachelor degree project in Product Design Engineering

Level G2E 30 ECTS

Spring term, year 2020

Authors:

Antonio Amor Muñoz

Matías Fernández Cranz

Supervisor: Aitor Iriondo Pascual

Assistant supervisor: Estela Pérez Luque

Examiner: Anna Brolin

Assurance of own work

This project report has on 9/06/2020 been definitely submitted by Antonio Amor Muñoz and Matías Fernández Cranz to University of Skövde as a part in obtaining credits on basic level G2E within Product Design Engineering.

We hereby confirm that for all the material included in this report which is not our own, we have reported a source and that we have not – for obtaining credits – included any material that we have earlier obtained credits within our academic studies.

Antonio Amor Muñoz   **Matías Fernández Cranz**

Abstract

Work-Related Musculoskeletal Disorders (WMSDs) are a common occupational health problem among healthcare workers. The emergence of new technologies such as motion capture offers a new approach to the study of the work conditions. This research studies the situation of nurses and surgeons both through the use of motion capture and traditional manual modelling of digital manikins. The research has been carried out through the study of six tasks, four of which performed by nurses and two by surgeons. Tasks have been selected after a literature review and interviews with surgeons and nurses. The six tasks have been evaluated using two software: Jack Tecnomatix, whose input was manual modelling of manikins following observational techniques; and IPS IMMA, whose input was motion capture files captured through Xsens Motion Trackers Awinda and processed with MVN Analyze. Results indicated that the tasks analysed were potentially harmful to workers, being the trunk and upper limb regions the ones that comprised higher levels of risk.

Table of Contents

1   INTRODUCTION

The conception and development of design projects encompass a set of tasks of very different nature, from purely investigative to administrative or economic-related. These tasks must be well put together and followed along the process to achieve quality outcomes. Product design engineers are involved in most of these tasks, especially in those referred to the conception and selection of new ideas and methodologies to guide the process.

A common way to tackle design problems is the user-centred design process, which comprises a methodology that puts the focus on the users and their needs all along the design process (Unruh and Canciglieri Junior, 2018). It starts by understanding the context in which the project is going to be carried out and the product used (stage A in Figure 1)—observational studies, interviews and questionnaires usually become useful in this phase—. Then, an identification of the user needs (stage B in Figure 1) must be put into the requirements of the design (stage C in Figure 1). These two phases set the frame that characterizes the project here presented. The process finishes with the embodiment of these requirements in a specific design solution (stage D in Figure 1), and is followed by an evaluation and verification phase (stage E in Figure 1). The design solution is, in a last resort, implemented (stage F in Figure 1). User-centred design processes have a strong iterative profile, in which user insights and feedback become crucial for the efficiency and productivity of each one of these iterations. (Richter and Flückiger, 2014).
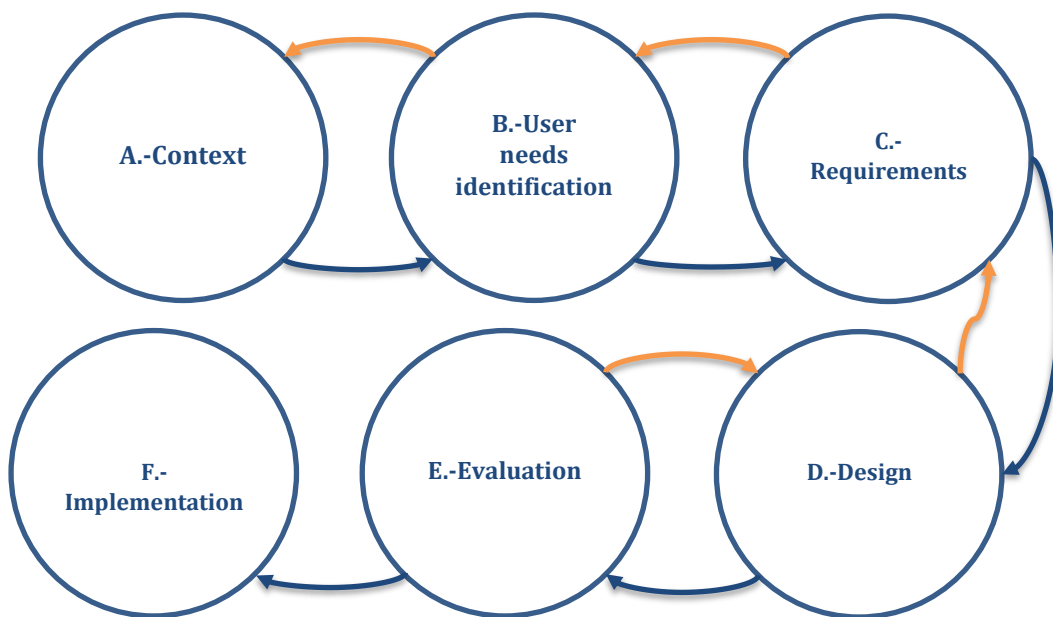
Fig. 1. Proposal of user-centred design process

On its behalf, ergonomics-related issues set their foundation in the design-human relation and, even though sometimes it is taken for granted, it could be the reason why a design would not succeed. (Taveira and Smith, 2006)

The following sections serve as a general frame to put the reader in context. First, the organizational environment will be presented. Second, the problem and

purpose of the project will be described. Lastly, a brief guide on how the report is structured is included.

1.1 ORGANIZATIONAL ENVIRONMENT

The project here presented is going to be carried out along with the User-Centred Product Design research group (UCPD) at the University of Skövde, in association with the Department of Health Science, which will provide valuable information. Access to specific software, equipment, and facilities will be provided by the University of Skövde.

1.2 PROBLEM

Work-related musculoskeletal disorders (WMSDs) caused by poor working conditions can be found in pretty much every discipline, from construction to administration, and are one of the main causes of sick leave in jobs (Jansson and Alexanderson, 2013).

Risk of injury caused by medical practices has been already studied by several authors and organizations and the impacts on well-being have been demonstrated. Moreover, these studies show that the work of nurses and assistant nurses seem to be the most potentially hazardous due to being in contact with patients more frequently than surgeons or office workers (Arvidsson et al., 2016; Menzel et al., 2004; Soylar and Ozer, 2018).

Repeated actions related to the manual handling of patients and work done in static awkward postures seem to be the main factors leading to injuries and musculoskeletal disorders in nurses, while maintenance of static postures for long periods of time and hand and fingers exertions affect surgeons in a higher manner (Waters et al., 2009)

1.3 PURPOSE

The aim of this project relates to the identification of the specific practices that lead to the appearance of musculoskeletal disorders in medical staff, their evaluation and risk assessment.

In terms of technical development of the project, the application of the motion capture system for human motion recording along with the implementation of computerized evaluation through Digital Human Modelling software would also constitute a central part of it.

Comparison between the application of motion capture and manual modelling in the creation of digital humans; consideration of the anthropometric diversity and comparison between RULA and OWAS when evaluating the same tasks are also objectives of the project.

1.4 STRUCTURE OF THE REPORT

Due to the strong experimental profile of the project, the structure used for its development is going to be formed by:
- A review of the available literature to get to know what the 'state of the art' is.
- An explanation of how the project has been developed

- A presentation of the results got and the conclusions they have led to.
- A discussion on the outcome and a proposal of ways to deal with the results got.

2 BACKGROUND

Nowadays, work conditions have experienced an upgrade compared to the ones from decades ago, and their growth keeps going. Even though some of the most demanding works have been replaced or complemented by the use of machines, the action of human factors to perform most of the tasks within the healthcare industry is still necessary. These tasks usually imply physical exertions and repetitive motions that could extend for long periods of time. Such a demanding situation not only causes physical disorders but can also affect in a psychological manner (Rugulies et al., 2004).

Although the most obvious physically demanding jobs—such as the related with the construction industry, farming, or mining—are normally observed with worry in terms of potential injuries or disorders; the truth is that many other works, apparently less harmful—e.g. office jobs, educational-related, healthcare-related—, also mean a health hazard. Frequently, these health risks are embraced by the own workers as an inherent part of the job they are developing, or are even unknown by them. In this sense, numerous studies seem to point out that subjective assessment—normally based on questionnaires and self-reports—provides a more optimistic view of the potential risks than the observed through observational methods (Hanson et al., 2001; Homan and Armstrong, 2003; Janowitz et al., 2006).

Due to these situations, many studies have been carried out over the years aiming to improve the working conditions in different industries. To do this in a systematic and reliable way, specialists such as ergonomists and practitioners have proposed different methods to assess these working situations, most of them focusing on physical factors—e.g., postures or loads—and the minority of them in both physical and psychosocial variables, such as work organization, interpersonal relations or discrimination at work (Aust et al., 2007; Rugulies et al., 2004).

Technological development in the last couple of decades has led to the creation and implementation of digital tools for the simulation and evaluation in the field of ergonomics. In this sense, Digital Human Modelling and direct measurement methods seem to be a powerful tool to improve the human-design relation of both new and existing designs (David, 2005; Duffy et al., 2008).

3   LITERATURE REVIEW

In this section, the information got from scientific articles, books, and research journals is exposed. Three areas of study have been considered to have a major relationship with the project's nature: ergonomic evaluation methods; Digital Human Modelling; and studies previously developed in hospitals.

3.1   ERGONOMIC EVALUATION METHODS: SELF-REPORTS, OBSERVATIONAL METHODS, AND DIRECT MEASUREMENT METHODS

Ergonomic evaluation methods have conventionally been classified by different authors into three categories depending on their nature and implementation technique: self-reports, observational techniques, and direct measurements (David, 2005; Spielholz et al., 2001).

3.1.1   Self-reports

Self-reports gather a quick and straightforward set of techniques for data collection. They are used to assess exposure at work based on data obtained from interviews with workers, questionnaires, or diaries. Usually, the development of these techniques is carried out using written methods, but nowadays it is common to find them as web-based questionnaires or self-evaluation from videotapes (David, 2005). Self-reports are also used as a way to gather information related to demographic factors like height, weight, or age for statistical purposes. In practice, there have been remarkable applications of these data collection methods like the one carried by Balogh I *et al.* (2001) on 14,556 subjects to study the relation between mechanical exposure of the shoulder-neck region and shoulder-neck pain. This specific study drew interesting conclusions due to the big sample employed.

Self-reports are often applied along with observational or direct measurement methods and used as the first step to obtain massive information from the study sample or to filter and arrange subjects based on different characteristics. Moreover, the data is used to make comparisons between different groups and over time.

According to David (2005) and Grooten and Johansson (2018), the main problem of using these methods rely on the imprecise conception the subjects have over the exposure they experiment, which leads to the necessity of using large sample sizes to get reliable data from the study case. It is common that workers experiencing some sort of WMSDs, perceive their work at a higher level of intensity, frequency, and duration compared to those with no record of WMSDs. In addition, self-report methods have a comparatively low cost, which makes them a very appropriate way to get quick and useful information in the beginning of the evaluation process, to use it in combination with other methods for a more detailed analysis (David, 2005).

Some authors have presented standardized questionnaires for the assessment of risk exposure, being one of the most used the Nordic Questionnaire for MSDs symptoms (Kuorinka et al., 1987), which is presented in two sections, one for general purposes and the other focusing on the low back and neck/shoulder area. Another widely accepted questionnaire was created by Hollman *et al.* (1999) based on the Dortmunder Biomechanical Model of the Spine. After extensive investigation on the validity of the test, it has been demonstrated to be useful and reliable (Janowitz et al., 2006).

3.1.2 Observational techniques

Grooten and Johansson (2018, p. 13) define observational techniques as 'methods based on concepts of an external observer (preferably an ergonomist) who fills in a predefined scoring sheet while watching a worker performing his/her work'.

As explained by Grooten and Johansson (2018), observational methods are, out of the three main assessment methods, the most useful for evaluating ergonomic risk in work environments on a daily basis. In turn, David (2005) proposes a classification of observational methods into simpler and advanced techniques, which will be introduced in points 3.1.2.1 and 3.1.2.2.

A study carried by Lowe et al. (2019) showed a prevalence in the use of certain observational methods in a sample of 405 certified ergonomists and practitioners from the U.S., Great Britain, Canada, Australia, and New Zealand.

The study revealed that the most frequently used methods were:

- NIOSH Lifting Equation (Waters et al., 1993)
- Rapid Upper Limb Assessment (RULA) (McAtamney and Nigel Corlett, 1993)
- Psychophysical Upper Extremity Data (Snook and Ciriello, 1991)
- Rapid Entire Body Assessment (REBA)(Hignett and McAtamney, 2000)
- Strain Index (Moore and Garg, 1995)

In addition, there are some other methods that, despite being used with less frequency by specialists, can be useful depending on the nature and purpose of the investigation —e.g. Ovako Working Posture Analysing System (OWAS) (Karhu et al., 1977), OCRA (Occhipinti. E, 1998), Quick Exposure Check for work-related musculoskeletal risks (QEC) (Li and Buckle, 2016), LUBA (Kee and Karwowski, 2001), and PLIBEL (Kemmlert, 1995)—

Grooten and Johansson (2018) consider the three main key issues of biomechanical exposure as intensity (force and posture), frequency, and duration. Table 1 summarizes the most common observational evaluation techniques and the parameters considered by each one of them:

Table 1. Most common observational techniques and parameters considered.

METHOD	BODY PART	INTENSITY	FREQUENCY	DURATION
NIOSH	Upper body	Force and posture	Yes	Yes
RULA	Upper body	Force and posture	No	No
REBA	Whole-body	Force and posture	Yes	No
STRAIN INDEX	Hand, lower arm	Force and posture	Yes	Yes
OWAS	Whole-body	Force and posture	Yes	No
OCRA	Upper extremity	Force and posture	Yes	Yes
QEC	Upper body	Force and posture	Yes	Yes
PLIBEL	Whole-body	Force and posture	No	No
LUBA	Upper body	Posture	No	No

3.1.2.1 Simpler observational techniques

Grooten and Johansson (2018, p. 13) define simpler observational techniques as 'methods based on concepts of an external observer (preferably an ergonomist) who fills in a predefined scoring sheet while watching a worker performing his/her work.' Simpler observational techniques are used for the direct evaluation of working postures, assessed by an observer in comparison with pre-established values. Depending on the selected technique, different exposure factors would be evaluated, ranging from just physical factors from a specific area of the body to both physical and psychosocial ones. In addition, simpler observational techniques are suitable for the assessment of static postures and repetitive movements. The application of simpler observational techniques has a relatively low cost, and return very reliable information due to the comparison data being already contrasted.

A scoring system is commonly used in some of these techniques —e.g. RULA, REBA, or OWAS—, being the returned value related to the necessity of intervention in the situation studied. This system is known as the 'traffic light' system because the situations' risk exposure can be classified according to the colours:

- Green: no intervention needed
- Yellow: intervention needed soon
- Orange (intervention required as soon as possible), although not used in every technique, is sometimes added to this classification and located between yellow and red.
- Red: immediate intervention required

Different types of methods put their focus on assessing specific parts of the body—e.g. RULA (McAtamney and Nigel Corlett, 1993) focuses on assessing the upper body, Strain Index (Moore and Garg, 1995) centres on evaluating the risk for the upper limbs, and REBA (Hignett and McAtamney, 2000) assesses both the upper and lower body. Therefore, the parameters considered by each one of the evaluation techniques must be investigated before selecting one, in order to get the most valuable information out of it.

3.1.2.2 Advanced observational techniques

Advanced observational techniques are used to assess highly dynamic activities. Data is recorded by videotaping or computer and analysed through special software capable to carry out calculations of positions, velocities, and accelerations of several joint segments simultaneously (David, 2005). The analysis is usually aided by biomechanical models, which are computerized representations of the human body as a set of articulated segments linked together, forming a kinetic chain.

Advanced observational techniques have shown to be useful for efficiently considering ergonomics throughout the development process in design projects. In addition, a remarkable advantage when working with advanced observational techniques is the verification of products and production lines ergonomics through the inclusion of anthropometric diversity in the study (Bertilsson et al., 2010).

However, the implementation of advanced observational techniques is usually quite expensive and require highly qualified staff for technical support. In contrast to simpler observational techniques, advanced observational techniques are more time-consuming but return highly detailed information (David, 2005).

3.1.3   Direct measurement techniques

Direct measurement methods for ergonomic assessment purposes refers, according to David (2005, p. 192), to: "methods that rely on sensors that are attached directly to the subject for the measurement of exposure variables at work."

The instruments used for measuring purposes range from devices capable to measure angles between two segments of the body to others that record data for several joints at a time during the performance of a task.

Table 2 presents the most common instrument for direct measuring and their utility for ergonomic evaluation purposes.

Direct measurement techniques gather the most novel processes on data collecting for risk exposure assessment. However, Grooten and Johansson (2018) point out that direct measurement techniques are more expensive than observational techniques, need for experts to be implemented in the studies, and can interfere with the organization's usual workflow.

Table 2. Instruments used for direct measurement.

Instrument	Function
Electronic goniometers	Measures the angle between two segments
Electronic torsiometers	Measures the amount of twist of a segment
Inclinometers	Measures an angle with respect to a plane of reference
Accelerometers	Measures the acceleration of a segment
EMG (Electromyography)	Records force and tensions supported by muscles during exertion.
LMM (Lumbar Motion Monitor)	Tri-axial goniometer that records data of position, velocity, and acceleration of the trunk. Used for back posture assessment.

3.2 DIGITAL HUMAN MODELLING (DHM)

Digital Human Modeling (DHM) can be defined as a "digital representation of the human inserted into a simulation or virtual environment to facilitate prediction of safety and/or performance", what can include visualization and "math or science in the background" (Duffy et al., 2008, p. 1)

It is important to tackle the ergonomic issues in the early stages of the product development cycle so that the final user or worker does not run the risk of using a dangerous product that can affect his or her health. It would be desirable that most of the changes and improvements related to ergonomics were done using DHM as support, due to being cost-effective and timesaving. DHM is a great tool to consider ergonomics at this phase since the final design does not need to have been developed yet. (Chapanis, 1995; Duffy et al., 2008)It is important to tackle the ergonomic issues in the early stages of the product development cycle so that the final user or worker does not run the risk of using a dangerous product or system that can affect his or her health. It would be

desirable that most of the changes and improvements related to ergonomics were done using DHM as support, due to being cost-effective and timesaving. DHM is a great tool to consider ergonomics at this phase since the final design does not need to have been developed yet. (Chapanis, 1995; Duffy et al., 2008)

When considering ergonomics in design, it is common to refer to three different approaches. In particular, Don B. Chaffin (2008, pp. 2.2-2.4, as cited in Duffy et al., 2008) classifies them into the following groups:

- The traditional approach, which consists of consultation of traditional Human Factors guides, data sources, reference books, standards, etc.
- Building and testing prototypes of proposed designs with sample users.
- Virtual CAD prototypes developed with DHM to test a variety of proposed designs and user attributes.

Although the three methods presented above can complement each other, all of them have limitations. According to Chaffin (2008, as cited in Duffy et al., 2008), the traditional approach can provide useful information and guidelines, but it can become difficult to apply them to specific problems. On the other hand, building prototypes can be expensive and time-consuming, besides choosing a suitable sample of people can be arduous. What makes DHM interesting is that it can be applied to the specific considered problem and without the necessity of building a physical prototype, which could potentially reduce the economic cost of the project.

However, DHM is not only useful when the objective is to design something new from the beginning but can be also a great tool to evaluate existing products or work situations and environments. In this sense, models addressed to optimize product design and to evaluate real work situations and environments seem to be of different nature. According to Wang (2006), two different models can be distinguished depending on their approach: those based on 'design' or 'biomechanical parameters'. While the first could be used by designers to improve the design of a product, the second could help to "understand possible sources of discomfort". However, Wang also points out that internal biomechanical constraints "have not been adequately taken into account in digital human modelling". Although challenging, the use of DHM to evaluate discomfort seems to be a great way to analyse and learn about the origin of WRMDs in actual environments.

3.3 PREVIOUS STUDIES IN HEALTH CARE CENTRES

MSDs do not only affect the workers' health. As Soylar and Ozer (2018) state, the appearance of MSDs at work can end up causing a "severe impact on the quality of life and result in work constraint, absenteeism or even the want to change jobs".

Regarding the impact of WMSDs, the healthcare industry presents one of the highest numbers of work-related incidents and injuries (Janowitz et al., 2006). In 2001, the US registered an incidence rate of 8.8 per 100 full-time workers and an average incidence value of 5.7. This fact makes the healthcare and hospital industry the second most affected field within the private sector with 286,000 cases in 2001 (US Department of Labor Bureau of Labor Statistics, 2002).

A great number of studies has focused on the assessment of risk exposure of nursing personnel, since they are the most affected workers within the hospital industry in terms of musculoskeletal disorders (Arvidsson et al., 2016; Menzel et al., 2004; Soylar and Ozer, 2018). Studies carried both by Yan P et al. (2016) on 2851 nurses and Letvak et al. (2012) on 1171 nurses, revealed a prevalence of musculoskeletal disorders of 78.5% and 71% respectively. In addition, Bos E et al. (2007), in a study carried on 3169 nurses found out that 76% had lower back problems and 60% presented neck-shoulder problems.

Finally, Soylar and Ozer (2018) conclude in their review of studies of musculoskeletal disorders on nursing personnel that the prevalence of WMSDs was higher in operating rooms and intensive care units.

3.4 IMPLEMENTATION

The topics discussed in this literature review have been thoughtfully selected to set the frame of reference for the upcoming chapters. In this sense, all of them have a direct relationship with the purpose of the project and will be applied during its development, as explained below. The combination of theoretical, technical, and practical content fully covers the necessary aspects to back up the decisions taken in the following parts.

For this matter, discussing the main evaluation methods for postural risk assessment (David, 2005) was the first step of this literature review. These three techniques—i.e. self-reports, observational techniques, and direct measurement methods—will be introduced and applied in our project in the following manners:

- Self-reports, discussed based on researches made by David (2005), Hollmann et al. (1999), Janowitz et al. (2006), and Kuorinka et al. (1987), and shaped as interviews and questionnaires, will set the starting point of this project's investigation. Information given by the group of study—i.e. healthcare personnel at hospitals and health care centers—will be important to fully understand the problem in their specific context and rearrange it in the most appropriate way.
- The way the studies will be developed make of the observational techniques (David, 2005; Grooten and Johansson, 2018; Karhu et al., 1977; Lowe et al., 2019; McAtamney and Nigel Corlett, 1993) a big cornerstone of the project. The correct selection of the methods for assessing each one of the tasks and postures will be of great importance to get the most realistic outcome. For this purpose, the available evaluation methods, as well as the variables that intervene in each one of them, have been looked into.
- Lastly, direct measurement methods encompass the main source of information to carry out this study. Tasks executed by healthcare personnel will be recorded

through the Xsens' motion capture system MTw Awinda and, aided by DHM software, evaluated (Grooten and Johansson, 2018; Xsens Technologies B.V., 2018).

A strong investigative profile can be drawn from the first part of this project; however, its practical deployment is characterized by its technical side. Digital Human Modelling (DHM) (Duffy et al., 2008) encompasses a methodology in which this study will strongly rely on. Employing software and instruments related to the purpose of the project will make a big difference in the final quality of this work. Finally, the most recent studies (Arvidsson et al., 2016; Bos E et al., 2007; Janowitz et al., 2006) on the relationship between musculoskeletal disorders and work demands on healthcare personnel have been analysed in section 3.3 to set an adequate starting point for the development of this project.

4 METHOD

The approach taken to develop the project starts with the definition of the group of study and finishes with the simulation and evaluation of work conditions, as described in the following lines. A diagram of the method workflow is included in Fig. 2 for a better understanding.

The following lines describe the steps to follow:

1) The group of study will be set, notwithstanding that it may undergo modifications according to actual access to the healthcare personnel at all times.
2) A data collection process will be developed. On the one hand, an interview with a public health specialist nurse and lecturer at the University of Skövde will be conducted, in order to know the material, physical and human resources that will be available for this study. On the other hand, interviews and questionnaires to nurses and surgeons will be designed. The objective is to know first-hand potential risks to the health of workers, thus combining the knowledge acquired thanks to the literature review with opinions and experience of the healthcare personnel involved in this project.
3) Based on the interviews and questionnaires, three personas will be developed. These characters will embody the tasks that will later be simulated.
4) Anthropometric diversity will be considered through the creation of manikin families based on two out of the three personas.
5) Concrete tasks and postures that will be simulated for evaluation will be established.
6) Ergonomic evaluation of the selected tasks will be carried out. For this purpose, the input will be obtained in two ways: 'directly', using the motion capture system Xsens and 'manually', modelling the postures using Jack Tecnomatix.
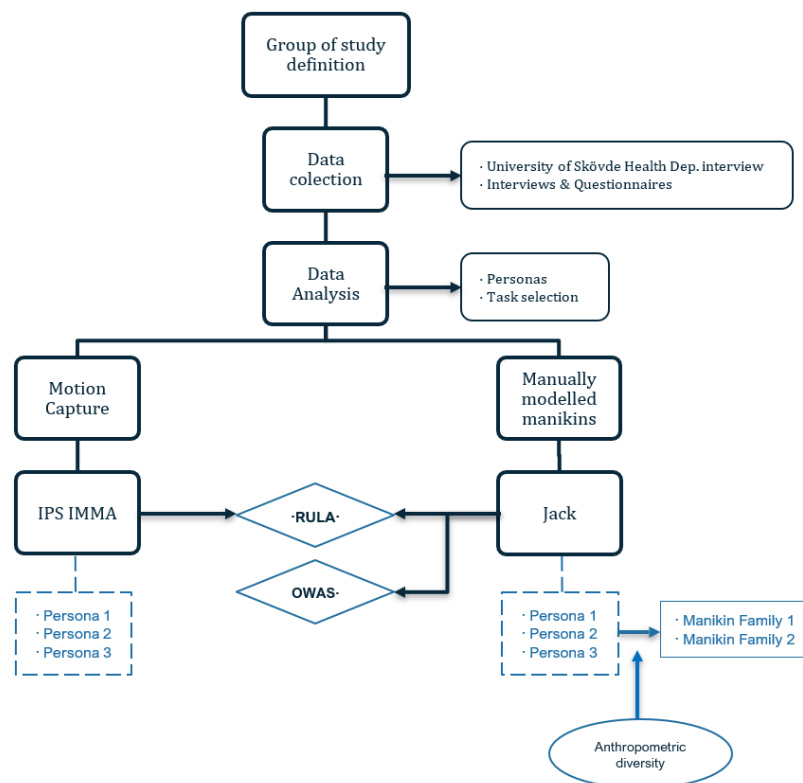
Fig. 2. Method workflow.

4.1. GROUPS OF STUDY

Among the wide variety of workers within the healthcare industry, surgeons and nurses have been selected as the object of study. These two groups of workers are in direct contact with the patient and must adapt themselves continuously to the patient's necessities. This may lead to adopting risky postures that can injure the worker in a medium or long-term, although work was tolerable and free of damage when done for a short period of time (Spath et al., 2006).

On the one hand, nursing personnel constitutes an interesting group of study within the healthcare industry for several reasons. First, nurses are, together with assistant nurses, those who spend more time in direct physical contact with patients (American Journal of Nursing, 1979). Second, their work involves many different but repetitive tasks that must be performed every day, for example: changing medication, putting catheters, or transferring and washing patients. Lastly, the need to put patients' care before their own comfort can result in oversight in the workers' health.

On the other hand, surgery personnel can perform operations ranging from 20 minutes to several hours. Often—*e.g.* laparoscopies—, surgeons must remain standing in static postures for long periods of time, where the only allowed movements are those to be performed with the upper limbs to continue with the operation (Vereczkei et al., 2004). It is possible to imagine that tension and stress levels can be considerable during certain situations in which the precision required is high.

According to Grooten and Johansson (2018), the three key factors that contribute to biomechanical exposure are frequency, intensity, and duration. It seems reasonable to think that, while nurses are more affected by factors as frequency and duration—due to routine tasks and great weights involved, respectively—, surgeons may be more affected by the intensity of the operations—where they must be focused in just one patient, often for several hours—. On this consideration, though, it will return throughout the study.

Considering all the above mentioned; knowing that available evaluation methods are more focused on assessing dynamic tasks (see Table 1 for comparison between factors); considering that tasks performed by nurses are more generic than those performed by surgeons—which are of very different nature depending on the speciality—; and knowing beforehand that access to nurses will be easier than to surgeons; nursing personnel will constitute the main group of study of this project.

4.2 DATA COLLECTION

Before starting the simulation and recording processes, it was important to choose which tasks and postures, performed by healthcare personnel, were going to be analysed since time and resources were limited. Besides the information provided by the literature review, the possibility of listening to actual healthcare workers' experiences and opinions was considered as potentially and particularly beneficial. The objective was to complement the scientific approach with first-hand information and to somehow assess the theory-pragmatism relation.

For this reason, interviews with both professionals from the Health Department of the University of Skövde and healthcare workers from different hospitals in the Canary Islands (Spain) were carried out.

4.2.1 Interview and questionnaire for nurses and surgeons

In order to gain first-hand information from workers whose tasks and postures will be studied later, two tools are going to be used:

- First, an interview has been designed in two variants: one for surgeons and other for nurses. There is a common part for both groups, consisting of demographic data, age, weight, height, that can be useful when evaluating postures. A second part has been specifically designed both for surgeons and nurses, attending the potential risks that each work can involve. For the design of the interviews, some studies carried out by Janowitz et al. (2006), and Rugulies et al. (2004) have been also considered.
- Secondly, a questionnaire in the form of a self-report has been designed. The objective is to identify the most common unsafe postures for the body.

In this way, interviews and questionnaires would respectively cover a qualitative and quantitative side of the data collection. Results from the interviews are exposed in sections 4.3.2 and 4.3.3.

4.2.1.1 *Interview*

As mentioned before, interviews for nurses and surgeons are aimed, not only to get information about the riskier postures and tasks performed by these workers but also to understand the context in which they are performed. Questions in both interviews cover almost the same matters, such as subjective vision or psychosocial aspects. These matters will be further explained in the following sections.

Questions have been drawn up from a number of categories, and are thus presented here for a better comprehension of the interview, its motivations, and goals. These categories, however, have not been shared with the interviewees, in order not to influence their answers. In contrast, interviews have been carried out in one go, allowing the interviewee to answer each question freely—although it implied answering another question at the same time—so that it was possible to get an insight into the problem.

Interviews have been designed trying not to bias the interviewee's answers. For this, before going to specific questions about risky postures or tasks—*e.g.* "What are the most physically demanding tasks?"—, first questions are addressed to know the subjective vision of the interviewee—*e.g.* "Do you think you have had pain due to your work?"—.

In general, questions have been made out as open as possible. It has been necessary, though, to ask about specific aspects, such as duration or intensity of some tasks, but always with the aim of letting the interviewees express themselves and tell everything they considered relevant.

Finally, it is known that the length of the interview is an important issue (Loosveldt and Beullens, 2013). Shorts interviews may not supply enough information; long interviews may mean a problem for the interviewee. In order to get enough and useful information, at the same time that it was possible to get participants (without the interview's length meant a hindrance), time was estimated between 20 and 40 minutes. Real interviews confirmed this estimation.

4.2.1.1.1 Interview for nurses

Questions are classified into the following categories:

- Demographic data. Useful data to classify interviewees. Data such as height or weight have an influence on the adopted postures.
- Subjective vision. First, questions aim to know the participant's opinion. Before asking for specific postural problems, it is advisable to know if the interviewee has ever considered ergonomics at work as a problem. Does he/she think that the way they work poses a health risk? Have they ever thought about it?
- Psychosocial aspects. An increasing number of studies indicate that psychosocial working conditions are a contributor to hospital workers' musculoskeletal disorders (Daraiseh et al., 2003). According to Aust *et al.* (2007), factors like "quantitative demands at work", "high work pace" and "work organization" seem to influence the appearance of WMSDs. This part of the interview does not aim to start a study about psychosocial factors and their influence in WMSDs—which would exceed the purpose of this project—, but it aims to know if a factor such as *work pressure* influence the quality of the postures nurses adopt.
- Intensity, duration, and frequency. As mentioned before (see 3.1.2), these are the three key factors (Grooten and Johansson, 2018) when it comes to assessing movements biomechanically.
- Previously identified problems. During the preceding literature review and analysis in general, several problems have been previously identified. The goal of these questions is to confirm or reject the importance of those problems.
- Improvements. Last, a question about potential improvements the participant may has thought about. This can also be a way to interpret which the participant's main concerns are.
- Free conversation. Although the interview tries to be open from the beginning, a space has been included to allow the worker to speak freely, about what he/she considers relevant.

4.2.1.1.2 Interview for surgeons

Changes in the questions' categories concerning the nurses' interviews are two:

- Psychosocial aspects. Nurses can be overworked when numerous patients arrive in a short period of time and the hospital is understaffed. Operations are different. Normally, they are scheduled; but even if they were emergency operations and there were more patients that surgeons, it would be very difficult that surgeons could leave a surgery room to enter in other, mainly due to sterilization issues. Therefore, that kind of work pressure does not affect equally to surgeons and, consequently, this question has been removed for surgeons' interview.
- Individual experience. While the tasks nurses perform are similar, among surgeons there are different specialization. Thus tasks, operations, demands, and postures can be very different if the surgeon is a neurosurgeon or a plastic surgeon.Different questions regarding the most hazardous tasks and postures they perform within their specialization have been included in this different category: individual experience.

Demographic data

Identification (A, B, C, etc.)	
Gender	
Age	
Weight (kg)	
Height (cm)	
Sitting acromial (cm)	
Acromial height (cm)	
Shift duration (h)	
Active years	
Speciality	
Centre	

Questions

Subjective vision
- Do you think you have had pain due to work? Where? Which tasks do you think influence that pain?
- Is there any posture that you consider to be especially tough? Which? In which context?
- Is there any task that you consider especially uncomfortable?

Psychosocial aspects
- Do you consider that time-related work pressure makes an impact on the quality of your postures? In which sense?
- Do you feel like the quality of your postures varies during your workday?

Intensity, duration & frequency

- Which are the most time-consuming tasks?
- Which are the most physically demanding tasks?
- Which are the most repeated tasks?

Previously identified problems
- Have you ever had postural problems while...
  - cleaning patients with reduced mobility?
  - changing patients from one bed to another or to a chair?
  - carrying patients in wheelchairs?

Improvements
- Any improvements?

Free conversation with nurses
Invite the interviewee to talk freely about his or her workday, conditions, problems. Enough recovery time between shifts?

Demographic data

Identification (A, B, C, etc.)	
Age	
Gender	
Weight (kg)	
Height (cm)	
Sitting acromial (cm)	
Acromion height (cm)	
Shift duration	
Active years	
Speciality	
Surgery room (specific operations)	
Centre	

Questions

Subjective vision
- Do you think you have had pain due to your work as a surgeon? Where?
- Which parts do you suffer the most during long operations? How many per week?
- Which parts do you suffer the most during short operations? How many per week?

Intensity, duration & frequency
- How many times do you operate a day? How many times per week?
- What is the operations' time span?
- Which are the most demanding operations? How often do you perform those operations?

Individual experience
- Which are the rarest or uncomfortable postures for the hands (or upper limbs)?
- Could you describe two postures (in context) that are especially uncomfortable?
- Could you enumerate the following parts according to the overall soreness experienced? Neck, shoulders, lower back, upper limbs, hands, and legs.
- Have you received training related to patient handling (referred to ergonomics) before? Do you apply the principles learned?

Previously identified problems
- Do you think that there are some external factors that compromise the quality of the ergonomics? Which ones? (surgical instruments, bed's height)

Improvements
- Any potential improvements?

Free conversation with surgeons

How many times a week do you operate? Routine (scheduled days for operations/medical consultations)

4.2.1.2   Questionnaire

While the information that interviews aim to gain is qualitative—since they are open and built in such a way that the participant can describe in detail the context—, the questionnaire presented below tries to get quantitative information. To complement interviews, a questionnaire in the form of self-report to be fulfilled by the interviewees has been added.

The objective is to measure which are the most common postures adopted by surgeons and nurses. For this, questionnaire data has demonstrated to be very useful if a high level of precision and detail is not required (Janowitz et al., 2006; Waters et al., 1993).

For this purpose, the Dortmunder questionnaire has been chosen. This questionnaire, technically based on the Dortmunder Biomechanical Model of the Spine, seems to be a widely accepted tool within the healthcare industry (Antolinos Guinart, 2016) and has demonstrated test-retest reliability when used in a health care setting (Janowitz et al., 2006). The specific model presented below is a modification made by Janowitz *et al.* (2006), based on the model by Hollmann *et al.* (1999).

The objective is to identify the most common ranges in which trunk, arms, and legs move. By doing this, attention will be put in those tasks framed in the most frequent ranges.

QUESTIONNAIRE MODEL

	Posture	Never	Seldom	Sometimes	Often	Very often
Trunk Posture						
	Straight upright					
	Bent half-way forward (about 45º)					
	Bent very forward (about 75º)					
	Twisted/rotated					
	Bent to the side					
Arm position						
	Both arms raised so that elbows are above chin height					
	One arm raised so that elbow is above chin height					
	Both arms raised so that elbows are above chest height					
	One arm raised so that elbow is above chest height					
	Both elbows below chest height					
Leg Position						
	Sitting					
	Standing					
	Squatting					
	Kneeling (on one or both knees)					
	Walking, moving					
Lifting pushing, pulling or carry with upright trunk posture						
	Light force (up to 11kg)					
	Moderate force (11-23 kg)					
	Heavy/high force (more than 23 kg)					
Lifting, pushing, pulling or carry with bent trunk						
	Light weight or force (up to 11 kg)					
	Moderate weight or force (11-23 kg)					
	Heavy weight or force (more than 23 kg)					

Fig. 3. Self-report form based on the Dortmunder model, modified from Klimmer and Hollmann (1999) (Janowitz et al., 2006)

4.3 DATA COLLECTION RESULTS

Results from the data collection are presented in three sections: results from the interview with the Health Department of the University of Skövde; results of the three interviews and questionnaires with nurses; and results from the three interviews and questionnaires with surgeons.

4.3.1 Health Department of the University of Skövde

An interview with a member of the Health Department of the University of Skövde was carried out. The interviewee, PhD, FNP, RN, is a registered nurse with a post-graduate diploma as a public health specialist in nursing, earned in a joint programme at the universities of Rhode Island and Skövde. She worked in end-of-life care in hospitals and outpatient care for special living and home care, and she is also a senior lecturer in nursing at the School of Health Sciences of the University of Skövde. Her numerous publications are mainly focused on older people in the home and their health and well-being.

The information got during the interview with can be summarized as follows:

- Access to surgeons and surgery rooms seems unrealistic due to extreme workload and difficulties in the implementation of the motion capture system in real operations.
- A better approach could include nurses and assistant nurses as the main group of study, since there could be access to the Clinical Training Centre at the University of Skövde and, to a lesser extent, educational units in the hospital.
- Special attention to physical problems caused by repetitive movements and focus on upper limb disorders (such as carpal tunnel syndrome) and low back area injuries.
- Other workers that could be considered for the study, due to their physical implications are occupational therapists, physicians and physiotherapists.
- Some physically demanding tasks, such as changing catheters, cleaning patients or turning them over on bed when they have spent too much time in the same position.
- Home healthcare personnel encompasses an interesting group of study due to difficulties in treating patients in non-professional environments.

4.3.2 Interviews and questionnaires with nurses

In total, three nurses have been interviewed by phone and have filled out the questionnaires by email. Their answers can be consulted in Appendix 10.1.

Interviews with nurses gave some relevant information:

- All the interviewees ensured to have experienced some sort of pain due to their professional activity.
- Patient handling tasks were considered especially harmful by all the interviewees.
- Lower back was the most referred region where the interviewees feel pain.
- All the interviewees declared to have received patient handling techniques training.
- Although knowing the correct techniques, all the interviewees stated that work pressure leads them to neglect their postures.

- The available time to dedicate to each patient influenced directly the time the interviewees dedicate to take care of their postures, e.g. adjusting bed height.
- All the interviewees stated that repetitive tasks, e.g. changing medication or putting catheters, have a strong impact on the global feeling of tiredness, although those tasks were not very physically demanding.
- All of the interviewees ensured that their postures were more neglected as the shift progressed.
- One of the interviewees considered home health care especially hazardous in contrast to hospitals, due to the lack of specialized equipment.

From the questionnaires, the information can be summarized in the following lines:
- All the interviewees stated to work with the trunk bent between 45º and 75º 'often' or 'very often'.
- All the interviewees stated to work with both elbows below chest height 'often' or 'very often'.
- All the interviewees stated to work 'walking/moving' 'very often', and 'seldom' to work seated.
- All the interviewees considered that they have to lift, push, pull or carry 'heavy weights (more than 23 kg)' with upright trunk 'often'.
- All the interviewees considered that they have to lift, push, pull or carry 'moderate weights (between 11 and 23 kg)' with bent trunk 'sometimes'.

4.3.3 Interviews and questionnaires with surgeons

Three surgeons have been interviewed by phone and have filled out the questionnaires by email. Their answers can be consulted in Appendix 10.1.

The following points summarize the information given in the interviews with surgeons:
- All the interviewees ensured to have experienced some sort of pain due to their professional activity.
- All the interviewees reported that the most affected regions are the lower back and neck regions.
- Regardless of the duration of the surgery, all the interviewees stated they suffer from the same regions of the body, i.e. back and neck.
- All the interviewees considered the shoulders as the third most affected area due to their professional activity.
- All the interviewees considered the lower limbs the less affected area due to their professional activity.
- All the interviewees described their tasks as mainly static.
- All of the interviewees considered the equipment used as correct.
- None of the interviewees received specific postural-related training to develop their job safely.

Regarding the questionnaires, the information is summarized in the following lines:
- All the interviewees ensured to work 'very often' with the trunk straight and 'sometimes' slightly bent.
- All the interviewees stated to work with the elbows below the chest 'very often'.
- All the interviewees stated to be normally seated or standing and never kneeling or squatting.

- All the interviewees stated not to lift weights greater than 11kg in their workplace.

4.4 PERSONAS

In a project, when it comes to clearly communicate the stakeholders the nature of the target group or, in this case, the group the study will be addressed to, 'personas' are useful tools to facilitate the task (Nielsen, 2019). It is believed that the use of personas facilitates empathy and understanding of the user needs (Preece et al., 2002).

In this case, the aim behind the development of personas was not only to communicate the profiles of healthcare workers in an easy and visual way, but also to structure and guide the ergonomic analysis throughout the project. Some aspects regarding the created personas are the following:

- Three personas were developed: two nurses and one surgeon. With the information collected in that moment, nurses seemed to be more potentially exposed to hazardous situations than surgeons, and real access to nurses was much easier than to surgeons.
- Personas were mainly based on the information provided by the interviews.
- Personas would have four sections:
  - *About*. Age, status, location, workplace, post and years of experience.
  - *Bio.* A brief story about the profile's work related to discomfort, injuries or soreness at work.
  - *Frustrations and Motivations*, related to his/her work. The objective is that the reader could empathize with the worker.
  - *Quotation*. A short quotation to sum up the worker's personality.
- Both the analysis through motion capture and through digital human modelling were characterized by these three personas.

4.4.1   Personas created

Personas 1, 2 and 3 are described in Fig. 4, Fig. 5 and Fig. 6. To represent these Personas during the simulations with IPS IMMA and Jack Tecnomatix, and perform the tasks during the recording session with Xsens sensors, three real people—actors—which could fit the profile of these Personas have been selected. Henceforth, the nomenclature used to refer to Personas 1, 2 and 3—embodied in the three real people selected—is going to be P1, P2 and P3, respectively. Measurements of the three actors used to represent the three personas are shown in Table 3. This information also served as input for motion capture purposes while setting up Xsens' MVN Analyze software.

Table 3. Measurements of the three actors representing the three Personas (all values in cm.).

Body part	Actress 1 representing Persona 1	Actor 2 representing Persona 2	Actor 3 representing Persona 3
Body height (cm)	176.0	193.0	188.5
Shoe length (cm)	26.7	32.0	33.5
Shoulder height (cm)	144.0	158.2	158.2
Shoulder width (cm)	33.2	41.5	40.7
Arm span (cm)	169.2	186.5	191.3
Hip height (cm)	100.8	100.0	185.0
Hip width (cm)	24.2	26.5	27.0
Knee height (cm)	51.9	52.5	58.0
Ankle height (cm)	9.5	8.8	10.5
Sole thickness (cm)	2.2	1.6	2.5

Persona 1

Persona 1, Lisa, and its description are displayed in Fig. 4.

Fig. 4. Persona 1 (see Appendix 10.2 for higher resolution).

Persona 2

Persona 2, Daniel, and its description are displayed in Fig. 5.

Fig. 5. Persona 2 (see Appendix 10.2 for higher resolution).

Persona 3

Persona 3, Daniel, and its description are displayed in Fig. 36.

Fig. 6. Persona 3 (see Appendix 10.2 for higher resolution).

4.5 ANTHROPOMETRIC DIVERSITY

In this project, some tasks performed by healthcare personnel will be analysed. For that, postures adopted in those tasks will be both modelled 'manually' using DHM software and captured 'automatically' using motion capture sensors. With these techniques, it is expected to achieve a high level of fidelity in the representation of real postures.

However, the whole process would be only applied to three profiles: the three personas mentioned in section 4.3. Therefore, the results of this study, although good, could hardly be extended to others than the personas studied.

To complement this study, anthropometric diversity will be considered through the creation, in the Jack software, of two families of digital manikins based, respectively, on personas 1 and 2. These personas match the nurses' profiles, which are the main group of study.

The family consists of six boundary manikins, representing the boundary cases. To define boundary cases, the confidence ellipse method will be used (Brolin et al., 2012). Two dimensions will be set as key dimensions:

- Sitting acromial (Jack)/shoulder height, sitting (antropometri.se).
- Acromion height (Jack)/shoulder height (antropometri.se)

4.5.1 Key dimensions

When nurses have to bend the back to treat patients in beds, the back´s length influence directly the effort supported by the erector spinae. A longer back will imply more weight far from the lumbar spine and hence will cause more momentum and more stress in the lower back. A shorter back will cause the opposite: a back´s centre of gravity closer to the lower back, less momentum and less stress. Hence, the measure "sitting acromial", eligible in Jack, IPS and the database provided by Hanson *et al.* (2009) is the selected to consider the back's length.

On the other hand, the subtraction of the sitting acromial from the acromion height results in the crotch height, which can be approximated for this Project to the length of the legs. The length of the legs is an important parameter since it marks the point where the back starts to bend and is related to the bed height. Representation of the two key dimensions is shown in Fig. 7.
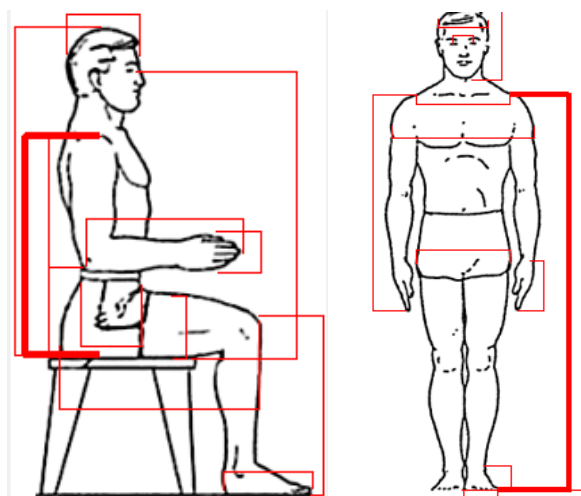
Fig. 7. Key dimensions. Sitting acromial (left) and acromial height (right). (Jack Siemens Tecnomatix)

4.5.2 Manikin families

Two families of manikins have been created, using a sample of Swedish men and women (Hanson et al., 2009). To avoid redundant cases within the ellipse boundary, the four central cases have been rejected. The confidence ellipse for a 95% confidence level, calculated through the website antropometri.se is shown in Fig. 8. Cases are numbered from 1 to 6, followed by the letter *f* or *m* depending on whether the subject is *female* or *male*, respectively.
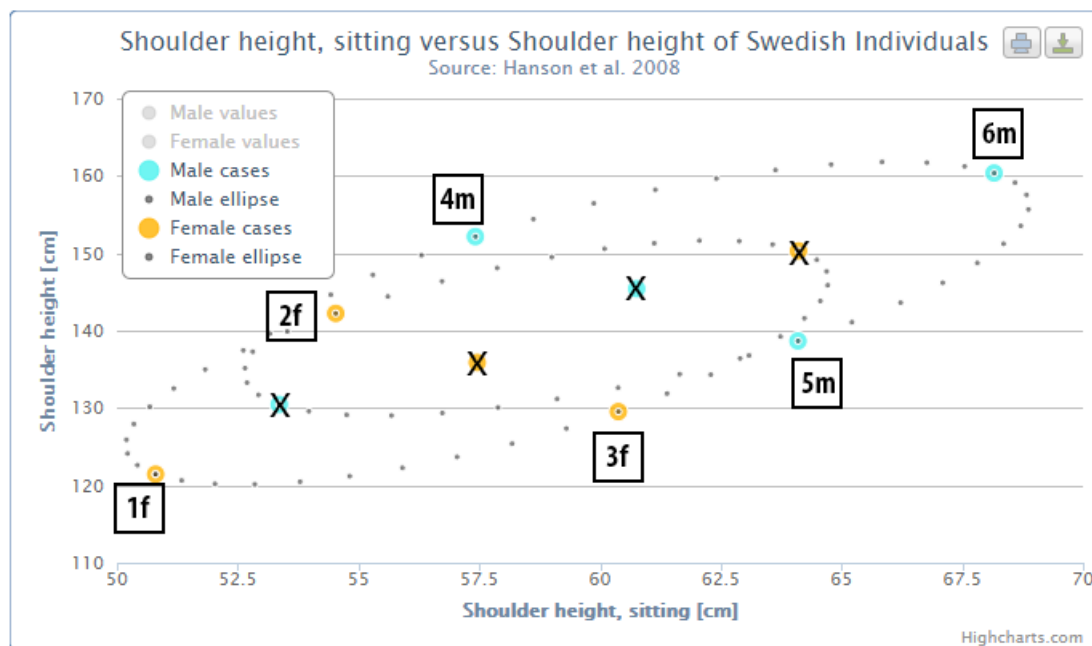
Fig. 8. Confidence ellipse for sitting acromial and acromion height. (Hanson et al., 2009; www.antropometri.se)

Values and percentiles of the two key dimensions for the 6 manikins studied are shown in Table 4.

Table 4. Values and percentiles of sitting acromial and acromion height. (Hanson et al., 2009; www. antropometri.se)

Conf. I = 95%	Sitting acromial		Acromion height	
	Value (cm)	Percentile	Value (cm)	Percentile
Case 1f	50.80	1.12	121.44	1.12
Case 2f	54.53	15.78	142.22	84.21
Case 3f	60.38	84.19	129.53	15.77
Case 4m	57.42	15.23	152.15	84.74
Case 5m	64.10	84.74	138.66	15.25
Case 6m	68.16	98.85	160.36	98.85

4.6 TASKS SELECTION

The task selection process encompasses an important part of this project due to the impact it will have on the representativeness of the results. Selection criteria bases on the following sources:

- Information got from the interviews and questionnaires done to nurses and surgeons (can be consulted in sections 4.3.2 and 4.3.3).
- Books and manuals of reference for consulting procedures and manoeuvres performed by nurses, such as *The Illustrated Guide to Safe Patient Handling and Movement* (Nelson et al., 2009) and *Manual de movilización de pacientes [Patients Mobilisation Manual]* (Martínez Fernández, 2009)*.
- Multimedia resources showing procedures and manoeuvres performed by surgeons, mainly in the shape of videos created by organizations like FREMAP.

The way the selection has been done results from the combination of information got from these three sources. Firstly, interviews and questionnaires served as a filter to know in which group of tasks to focus on. Not only the descriptions given by the interviewees were considered for choosing the group of tasks to study, but also information referred to the parts of the body they suffer the most was used to reduce the tasks to focus on.

For the nurses, the descriptions given were complemented with specific explanations found on reference manuals for manoeuvres and procedures. On the other hand, multimedia resources were used to complement the descriptions given by both nurses and surgeons on the tasks they found more demanding and risky. Concurrently, other tasks involving parts of the body from which the interviewees were affected were also taken into consideration.

4.6.1 Nurses tasks

In the following sections, the selected tasks for nurses are described.

4.6.1.1 Task 1. Patient lying in bed to seated on the side of the bed

Description of task 1 (view Fig. 9), patient laying in bed to seated on the side of the bed:

- Number of nurses involved: one.
- Instruments used to perform the task: none.
- Patient's initial position: laid close to the edge of the bed and facing up; arms crossed over the stomach; legs straight and crossed.
- Nurse's initial position: one hand behind the patient's back at shoulders height; the other one on the side of the leg that is further from him; legs and back slightly bent forward.
- Manoeuvre description: while the hand located behind the back of the patient lifts the upper body, the other one pushes the legs out and downwards.
- Patient's final position: seated on the side of the bed.
- Nurse's final position: standing straight with the torso slightly rotated to the side in which the patient sits; the hands remain in the same position as they started.
- Main body areas implied in the task (higher to lower implication): back and shoulders.
- Task character: dynamic.
- Task duration: negligible.

- Estimated workload (related to load supported): medium.

Fig. 9. Task 1. Initial, critical point and final position (FREMAP)

4.6.1.2 Task 2. Patient seated on the side of the bed to seated in a chair

Description of task 2 (view Fig. 10), patient seated on the side of the bed to seated in a chair:

- Number of nurses involved: one.
- Instruments used to perform the task: none.
- Patient's initial position: seated in the side of the bed; arms around the nurse's waist; head resting on the nurse's chest; and legs slightly open and fully in contact with the floor.
- Nurse's initial position: back and legs bent forward; arms around the patient's back below the shoulders; and one foot between the patient's feet.
- Manoeuvre description: the nurse lifts the patient until legs and back are fully extended, then a 90-degree rotation is performed and, by a flexion of the back and the legs performed by the nurse, the patient is carefully seated in a chair.
- Patient's final position: seated in a chair.
- Nurse's final position: same as the initial position.
- Main body areas implied in the task (higher to lower implication): back and shoulders.
- Task character: dynamic.
- Task duration: negligible.
- Estimated workload (related to load supported): high.
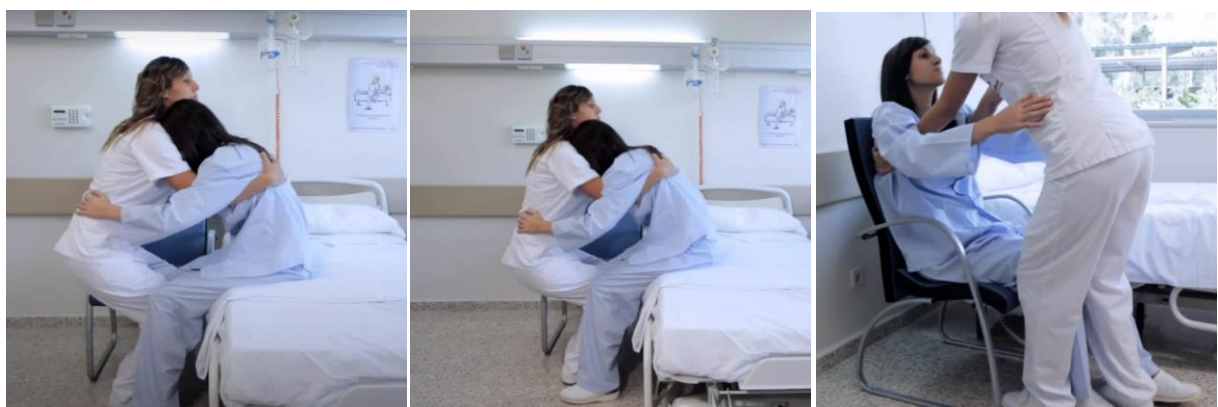
Fig. 10. Task 2. Initial, critical point and final position (FREMAP)

4.6.1.3   Task 3. Patient seated in a wheelchair to seated in a chair

Description of Task 3 (view Fig. 11), Patient seated in a wheelchair to seated in a chair:

- Number of nurses involved: two.
- Instruments used to perform the task: a towel.
- Patient's initial position: seated in a wheelchair; each arm over the shoulder of each one of the nurses at the sides.
- Nurse's initial position: each nurse at one side of the patient; facing opposite to the patient; back and legs bent forward until the patient is able to put the arms over their shoulders; one hand around the patient's waist and the other holding a towel located below the patient's thighs.
- Manoeuvre description: a towel is placed below the patient's thighs. The nurses lift the patient until they are fully extended, move close to the chair and, facing it, slowly lower the patient to a seated position.
- Patient's final position: seated in a chair.
- Nurse's final position: same as the initial position.
- Main body areas implied in the task (higher to lower implication): back, neck, shoulders, legs.
- Task character: dynamic.
- Task duration: negligible.
- Estimated workload (related to load supported): high.

Fig. 11. Task 3. Initial, critical point and final position (FREMAP).

4.6.1.4 Task 4. Patient reposition in bed

Description of Task 4 (view Fig. 12): patient reposition in bed.

- Number of nurses involved: two.
- Instruments used to perform the task: none.
- Patient's initial position: laid facing up; legs bent and feet fully in contact with the bed, arms crossed over the stomach.
- Nurse's initial position: one nurse in each side of the bed; facing the headboard of the bed; the arm that is further to the bed holds the headboard; the other arm is located in the patient's back at the height of the shoulder that is further to the nurse (so that the arms of the nurses are crossed and symmetrically supporting the back of the patient); the leg that is further to the bed is extended and touching the floor; the leg closer to the bed is bent and the knee resting on the mattress.
- Manoeuvre description: the nurses help themselves from the headboard and, in one synchronized gesture, drag the patient up to the top of the bed.
- Patient's final position: same as the initial position.
- Nurse's final position: same as the initial position.
- Main body areas implied in the task (higher to lower implication): back and shoulders
- Task character: dynamic.
- Task duration: negligible.
- Estimated workload (related to load supported): medium-high.

Fig. 12. Task 4. Initial and final position (FREMAP).

4.6.2   Surgeons tasks

In the following sections, the selected tasks for surgeons are described. These tasks, in contrast to the selected tasks for nurses, do not imply great loads. However, the necessity of holding the same posture, statically, during long periods of time, was reported by the interviewees as the main cause of soreness. Therefore, the evaluation of these tasks seems appropiate.

4.6.2.1   Task 5. Abdominal tissue separation

Description of Task 5, abdominal tissue separation:
- Number of surgeons involved: one.
- Instruments used to perform the task: long hook-ended rod.
- Patient's initial position: laid in a surgery bed; facing up; fully extended.
- Doctor's initial position: standing; back slightly bent forward and torso slightly rotated to one side; legs extended; the arm operating the instrument is flexed on a 70-90 degree angle in the sagittal plane; upper arm (from elbow to shoulder) raised in the coronal plane until creating a 60-70 degree angle with the longitudinal axis. Based on this position, the lower arm faces downwards and creates a 40-50 degree with the coronal plane.
- Manoeuvre description: the task consists on the separation of abdominal tissue to improve the visibility of other surgeons and nurses during the operation. A hook-ended long rod is attached to the part that is going to be pulled. The surgeon holds a constant pull.
- Patient's final position: same as the initial position.
- Doctor's final position: same as the initial position.
- Main areas of the body implied (higher to lower implication): shoulders, back, and lower arm.
- Task character: static.
- Task duration: 5 to 10 minutes.
- Estimated workload (related to load supported): low.

4.6.2.2   Task 6. Eye evaluation using 'slit lamp' machine

Description of Task 6 (view Fig. 13), eye evaluation using 'slit lamp' machine:
- Number of surgeons involved: one.
- Machine description: The 'slit lamp' machine is commonly used in ophthalmology as an exploratory method to evaluate and diagnose different view problems. It consists of a large vertical body placed on top of a table. Doctor and patient seat one in front of the other at each side of the machine, 50-60 cm apart. The patient bents forward and locates the chin and forehead in a support structure to be examined by the doctor with a microscope.
- Instruments used to perform the task: 'slit lamp' machine and interchangeable lenses.
- Patient's initial position: seated; bent forward with the head supported.
- Doctor's initial position: seated; bent forward; looking through lenses who serve as a microscope; with the arm almost fully extended and close to the patient's eyes. A hand extension of approximately 60-degrees is performed to locate the lenses parallel to the patient eyes.

- Manoeuvre description: doctor and patient seat one in front of the other, the doctor looks through a microscope and, extending the arm, put some lenses on the patient's eye to evaluate different aspects.
- Patient's final position: same as the initial position.
- Doctor's final position: same as the initial position.
- Main body areas implied in the task (higher to lower implication): back, shoulder, and neck.
- Task character: static.
- Task duration: 15 to 20 minutes.
- Estimated workload (related to load supported): low.

Fig. 13. Task 6. Two examples.

4.6.3 RULA and OWAS parameters

The implementation of the tasks in Jack for their evaluation implies the choice of some specific parameters, according to the requirements of each method. These parameters, for the RULA method, are shown in

Table 5.

Table 5. RULA parameters for each task.

RULA							
Category	Group	**Task**					
		T1	**T2**	**T3**	**T4**	**T5**	**T6**
Muscle use	A	Normal	Normal	Normal	Normal	Mainly static	Mainly static
	B						
Force load	A	2-10 kg intermittent load	More than 10 kg	More than 10 kg	More than 10 kg	<2 kg intermittent load	< 2 kg intermittent load
	B						
Arms		Not supported	Not supported	Not supported	Not supported	Not supported	Not supported
Legs		Standing. Weight even	Standing. Weight even	Standing. Weight even	Legs/feet not supported. Weight distribution uneven	Standing. Weight even	Seated. Weight even

Load parameters selected for each task for their use in OWAS as evaluation method are shown in Table 6.

Table 6. OWAS load parameters for each task.

OWAS						
Load	**Task**					
	T1	**T2**	**T3**	**T4**	**T5**	**T6**
Description	L < 10 kg	10 kg < L < 20 kg	20 kg < L	10 kg < L < 20 kg	L < 10 kg	L < 10 kg
Code	1	2	3	2	1	1

4.6.4 RULA and OWAS warning messages

As mentioned, two evaluation methods will be used: RULA and OWAS. The way in which each method presents the results is similar: a message and a colour. However, messages and colours are not exactly the same. For a better comprehension of the results and to allow comparisons between the results of each method, Table 7 summarizes the messages that each method gives (Brolin and Högberg, 2019; Karhu et al., 1977; McAtamney and Nigel Corlett, 1993).

Table 7. Comparison between messages of RULA and OWAS.

Category of action	Method					
	RULA			OWAS		
	System	Colour	Message	System	Colour	Message
1	Final score from 1 to 7	1-2	Acceptable	4 digits code, each of them regarding legs, back, arms or trunk		No action
2		3-4	Investigate further			Action in near future
3		5-6	Investigate further and change soon			Action as soon as possible
4		7	Investigate and change immediately			Immediate action

4.7 SIMULATION AND EVALUATION TOOLS

The motion capture system available for the development of this project is Xsens Awinda. It is composed by seventeen Motion Trackers (MTw), which are inertial measurement units containing 3D linear accelerometers, 3D rate gyroscopes, 3D magnetometers and a barometer (Xsens Technologies B.V., 2018).

As a way to explore how the nature of the input used for ergonomic evaluation processes affects the results, the present study is going to be carried out based on information received both from the use of motion capture systems and pure observation and video recordings to 'manually' emulate the postures in DHM software.

Table 8 shows a comparison between two common ways of getting input for ergonomic evaluation—i.e. motion capture systems and manual modelling in DHM software—related to the following aspects which were considered relevant:

- Realism: referred to how the simulation adjusts to the real movement.
- Accuracy: related to small errors that could affect the quality of the input.
- Study diversification: the ability to transfer the information from the seed input to other cases.
- Speed: the time spent on preparing both the manikin and the simulation for running the evaluation.
- Cost: cost of the equipment, tools or software needed.

- Need for previous steps: like measuring body dimensions, videotaping tasks or postures and treating the information to extract angles and distance.

Table 8. Comparison between input source for evaluation using digital techniques.

	Motion capture systems	Manual DHM
Realism	+	-
Accuracy	-	+
Study diversification	-	+
Speed	+	-
Cost	-	+
Need for previous steps	+	-

Symbol + (-) indicates better (worse) result in the specific aspect.

4.7.1 Input via motion capture systems

Once the tasks performed by nurses and surgeons have been captured, files must be processed using the software Xsens MVN Analyze. Then, files must be exported from Xsens MVN Analyze into a valid format for running them into the DHM software—e.g. Jack Tecnomatix or IPS IMMA—.

IPS IMMA will be the software used to carry out the tasks' evaluation using imported motion capture data. First, a 'single manikin' is created with the same anthropometric dimensions as the person whose motion has been recorded through Xsens. Second, an 'operation sequence' is created and the motion capture file is loaded, processed and linked to the manikin. Finally, the sequence is stopped in the most critical posture, according to the RULA graph implemented in the software—which represents RULA scores over time—.

4.7.2 Input via manual simulation in DHM tools

Manual modelling through DHM software will be performed using Jack Tecnomatix due to the variety of evaluation methods it presents. This would lead to a comparison between the results offered by each one of the methods employed and result in a more reliable assessment of the tasks.

Specifically, the methods that are going to be used for the risk assessment of the tasks will be RULA and OWAS, since they fit the tasks' characteristics—full body implied in their performance, high implication of the upper body, and load implication—

5 RESULTS

The sections here presented will summarize the results obtained in the different studies stated in chapter 4. Method:

- First, in section 5.1, results obtained through evaluation of the postures using the motion capture system Xsens, IPS IMMA software, and RULA method implemented in it will be presented. Similarly, in section 5.2, results obtained through evaluation of the postures modelled manually aided by the DHM software Siemens Jack, and using RULA and OWAS evaluation methods, will be shown.
- Second, differences between results obtained through two techniques used for representing the tasks, i.e. motion capture system and manual modelling using DHM software, will be presented in section 5.3.
- Finally, in section 5.4, results related to the three personas for each one of the tasks performed, will be summarized in the form of tables.

5.1 MOTION CAPTURE RESULTS

In the following sections, results from the RULA evaluation given by IPS IMMA when using motion capture files as input, are shown. Three pictures are also shown for each task and persona: a real photo of the task performed in the Clinical Training Centre of the University of Skövde; a screenshot of the manikin adopting the studied posture in MVN Analyze; and finally, a picture of the manikin in IPS IMMA, where RULA is applied.

In total, 10 tasks were simulated: 4 nurses' tasks performed by an actor representing Persona 1; the same 4 nurses' tasks performed by the actor Persona 2; and 2 surgeons' tasks performed by the actor that embodies Persona 3. Whereas MVN Analyze read all the sensors recordings with no problem, IPS IMMA read 8 out of 10 correctly. Thus, two results (Tasks 2 and 3 for persona 1) are considered invalid.

Results will indicate if nurses and surgeons are affected when developing the selected tasks. RULA results when using motion capture files or manually modelled manikins as input (using IPS IMMA and Jack Tecnomatix, respectively) will be compared, to know the influence that each type of input has. Results when using OWAS and RULA will also be compared, to get an insight into how each evaluation method assesses the same task, and which are the warning messages. All of these topics will be discussed in section 7. Discussion.

5.1.1 Nurses' tasks

Results for the nurses' tasks are shown in the following sections.

5.1.1.1 Task 1

In Fig. 14 and Fig. 15, real, MVN Analyze and IPS IMMA pictures of the evaluation of task 1 for personas 1 and 2 are displayed.
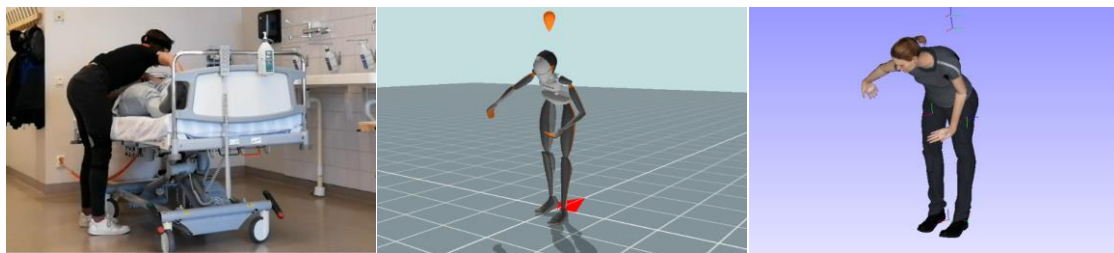
Fig. 14. Task 1, persona 1. Real, MVN Analyze and IPS IMMA pictures (left to right).
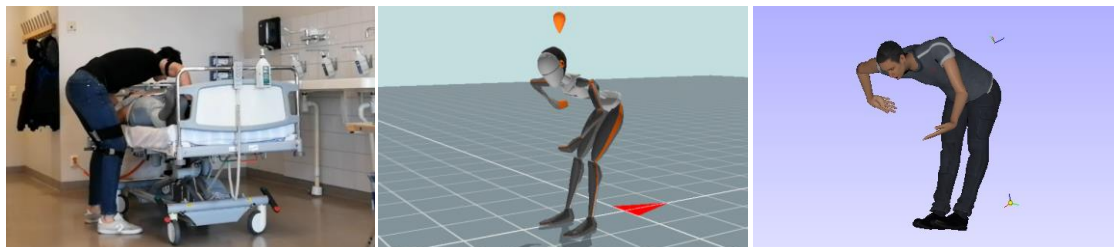
Fig. 15. Task 1, persona 2. Real, MVN Analyze and IPS IMMA pictures (left to right).

Results of the evaluation using RULA are shown in Table 9.

Table 9. Task 1. Evaluation results through RULA using IPS IMMA and motion capture files.

Task 1	
Case	**Method: RULA**
p1	4
p2	7

5.1.1.2 Task 2

In Fig. 16 and Fig. 17, real, MVN Analyze and IPS IMMA pictures are displayed of personas 1 and 2 performing task 2. As it can be seen in the picture on the right in Fig. 16, IPS IMMA

Fig. 16. Task 2, persona 1. Real, MVN Analyze and IPS IMMA pictures (left to right).
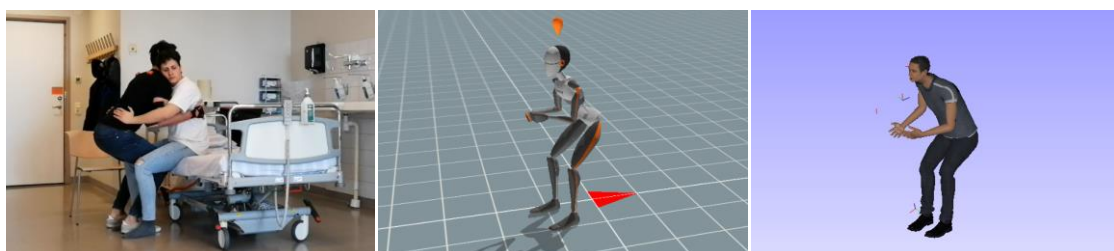
Fig. 17. Task 2, persona 2. Real, MVN Analyze and IPS IMMA pictures (left to right).

Results of the evaluation using RULA are shown in Table 10.

Table 10. Task 2. Evaluation results through RULA using IPS IMMA and motion capture files.

Task 2	
Case	**Method: RULA**
p1	-
p2	7

5.1.1.3 Task 3

In Fig. 18 and Fig. 19, real, MVN Analyze and IPS IMMA pictures of personas 1 and 2 performing task 3 are displayed.
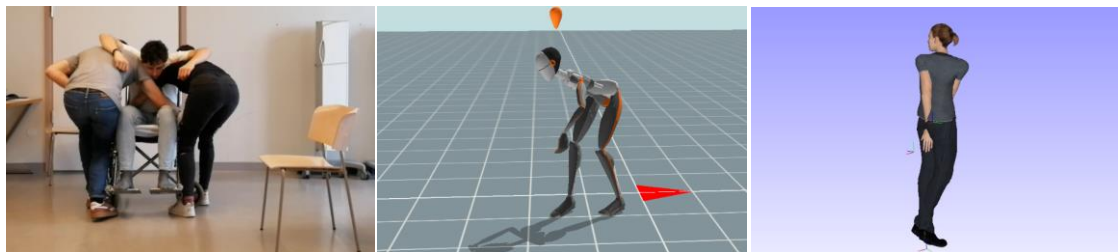
Fig. 18. Task 3, persona 1. Real, MVN Analyze and IPS IMMA pictures (left to right).
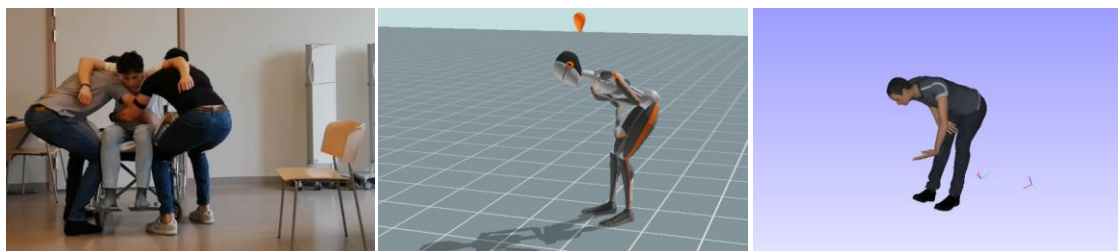
Fig. 19. Task 3, persona 2. Real, MVN Analyze and IPS IMMA pictures (left to right).

Results of the evaluation using RULA are shown in Table 11.

Table 11. Task 3. Evaluation results through RULA using IPS IMMA and motion capture files.

Task 3	
Case	**Method: RULA**
p1	-
p2	7

5.1.1.4 Task 4

In Fig. 20 and Fig. 21, real, MVN Analyze and IPS IMMA pictures of personas 1 and 2 performing task 4 are displayed.
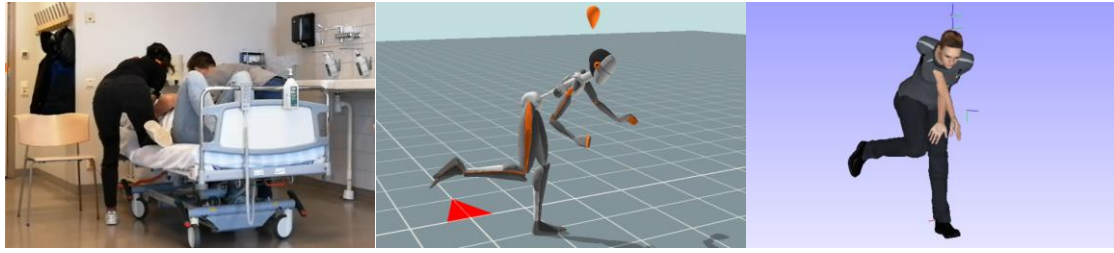
Fig. 20. Task 4, persona 1. Real, MVN Analyze and IPS IMMA pictures (left to right).
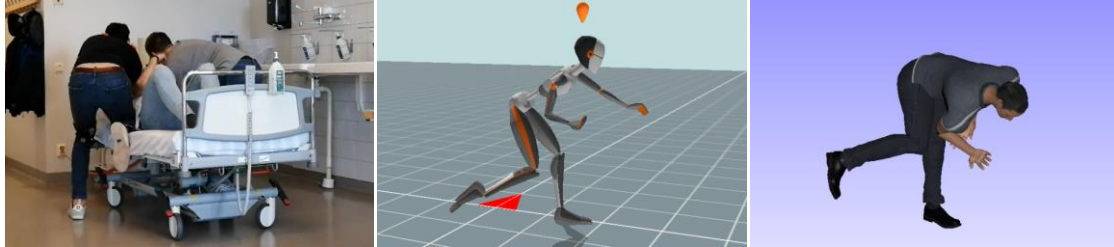
Fig. 21. Task 4, persona 2. Real, MVN Analyze and IPS IMMA pictures (left to right).

Results of the evaluation using RULA are shown in Table 12.

Table 12. Task 4. Evaluation results through RULA using IPS IMMA and motion capture files.

Task 4	
Case	**Method: RULA**
p1	7
p2	6

5.1.2   Surgeons' tasks

Results for the surgeons' tasks are shown in the two following sections.

5.1.2.1   Task 5

In Fig. 22, real, MVN Analyze and IPS IMMA pictures of the persona 3 performing task 5 are displayed.
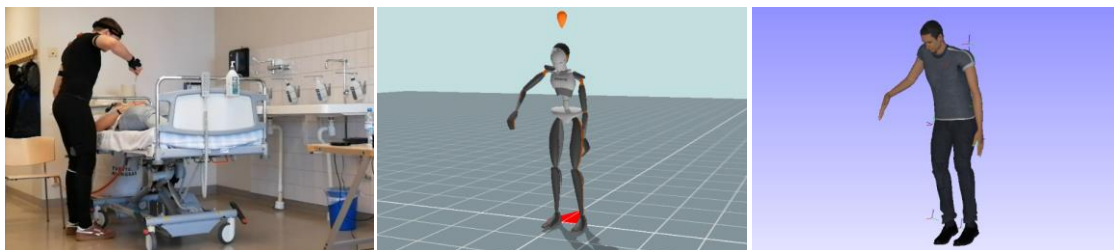
Fig. 22. Task 5, persona 3. Real, MVN Analyze and IPS IMMA pictures (left to right).

Results of the evaluation using RULA are shown in Table 13.

Task 5	
Case	**Method: RULA**
p3	3

5.1.2.2 Task 6

In Fig. 23, real, MVN Analyze and IPS IMMA pictures of the persona 3 performing task 6 are displayed. Observing the picture on the right and comparing it to the other two, it is clear that the posture has not been correctly interpreted by IPS IMMA, so results for this task were considered invalid.

Fig. 23. Task 6, persona 3. Real, MVN Analyze and IPS IMMA pictures (left to right).

Results of the evaluation using RULA are shown in Table 14.

Table 14. Task 6. Evaluation results through RULA using IPS IMMA and motion capture files.

Task 6	
Case	**Method: RULA**
p3	-

5.2 DHM RESULTS

In the following sections, evaluations for the critical postures of the tasks performed by nurses and surgeons are shown. Postures have been modelled 'manually' using the DHM software Jack, trying to faithfully represent real postures.

5.2.1 Nurses' tasks

For the nurses' tasks, postures have been analysed both for the two subjects created from Personas 1 and 2 (*p1* and *p2*), and for the six manikins created considering boundary cases of the confidence ellipse (*f1, f2, f3, m4, m5* and *m6*), as explained in section 4.5.2. Tasks 3 and 4 involve two nurses. Since postures adopted by the two nurses are symmetrical, and the forces implied are the same, only one nurse per task has been analysed.

5.2.1.1 Task 1

In Fig. 24, personas 1 and 2 modelled in Jack, in the critical posture analysed for Task 1, are shown.
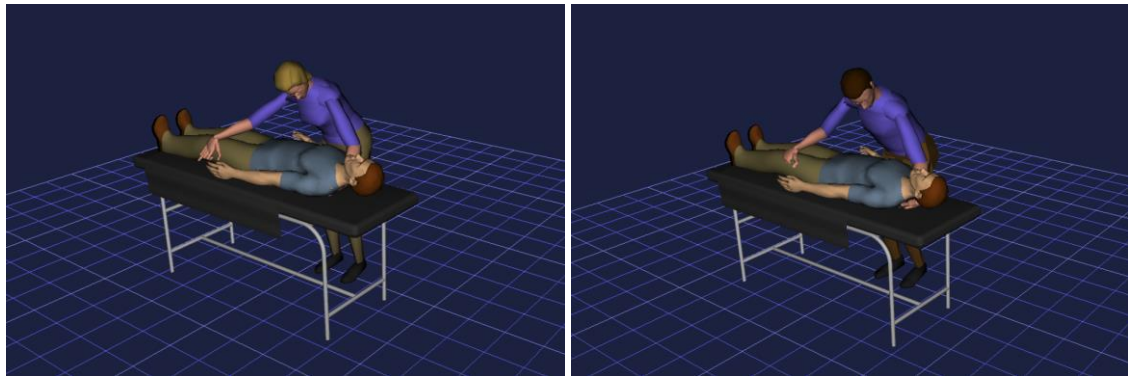
Fig. 24. Personas 1 (left) and 2 (right) in the posture analysed for Task 1

The six boundary cases, grouped in female and male cases, are shown in Fig. 25.
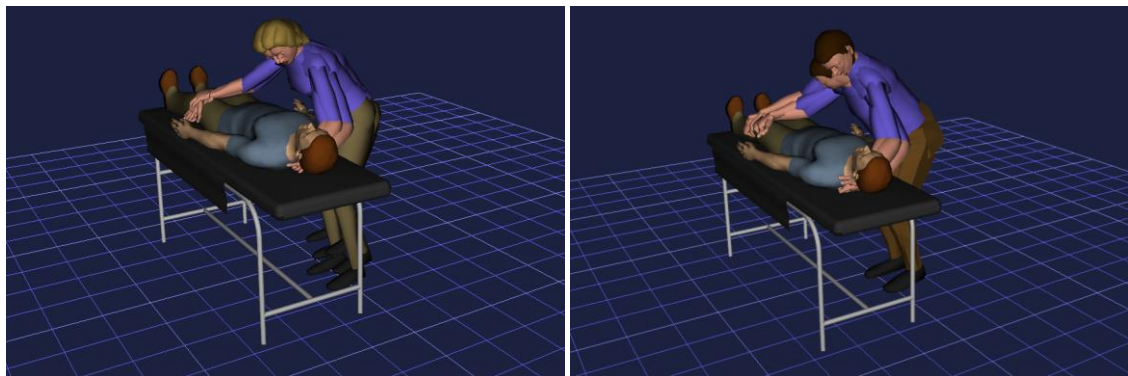
Fig. 25. Female (left) and male (right) manikins in the posture analysed for Task 1.

In Table 15, the final results of the evaluations for Task 1, using RULAS and OWAS in Jack, are shown.

Table 15. Task 1. Evaluation results through RULA and OWAS using Jack.

Task 1		
Case	**Method**	
	RULA	**OWAS**
p1	6	2141
p2	6	2141
f1	6	2141
f2	6	2141
f3	6	2141
m4	6	2141
m5	6	2141
m6	6	2141

5.2.1.2 Task 2

In Fig. 26, personas 1 and 2 in the posture analysed for the second task, are shown.
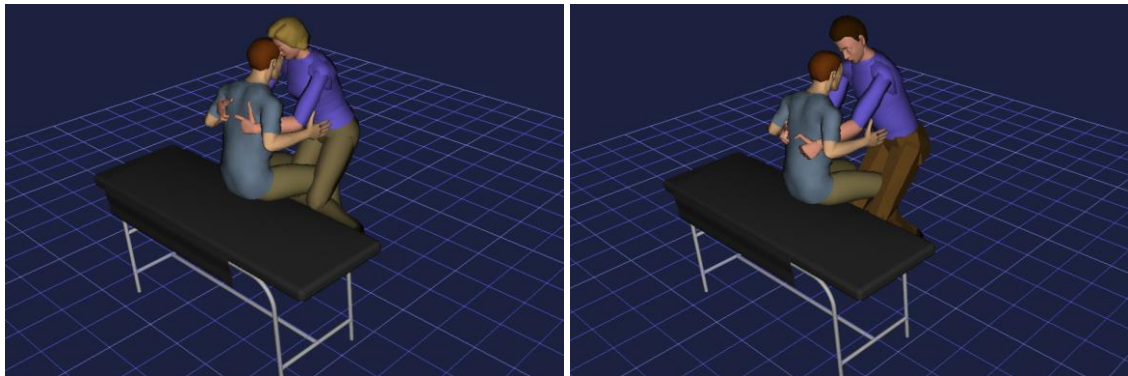
Fig. 26. Personas 1 (left) and 2 (right) in the posture analysed for Task 2.

The six boundary cases, grouped in female and male cases, are shown in Fig. 27.
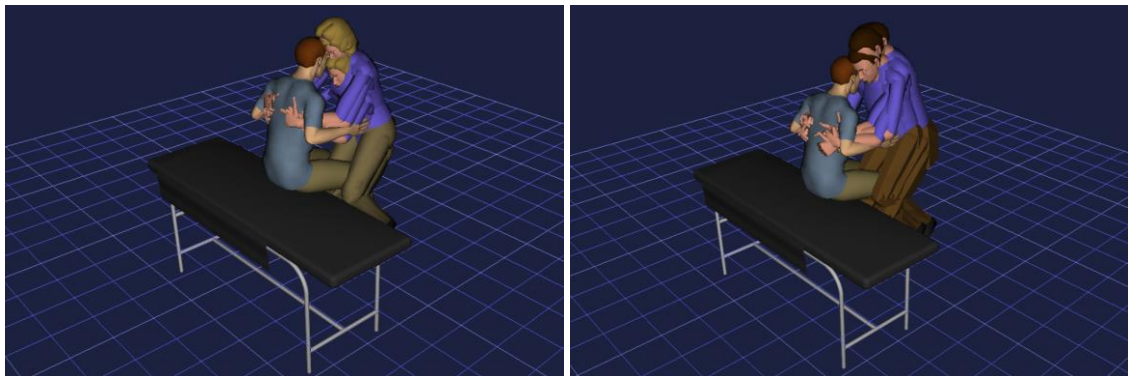
Fig. 27. Female (left) and male (right) manikins in the posture analysed for Task 2.

In Table 16, the results of the evaluation of Task 2, using RULA and OWAS in Jack.

Table 16. Task 2. Evaluation results through RULA and OWAS using Jack.

Task 2		
Case	**Method**	
	RULA	**OWAS**
p1	7	2142
p2	7	2142
f1	7	2142
f2	7	2142
f3	7	2142
m4	7	2142
m5	7	2142
m6	7	2142

5.2.1.3   Task 3

In Fig. 28, personas 1 and 2 in the posture analysed for the second task, are shown.
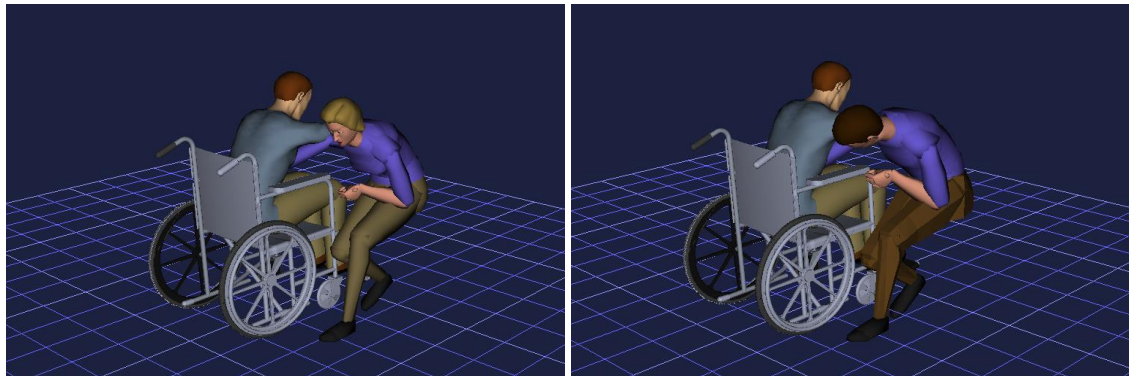
Fig. 28. Personas 1 (left) and 2 (right) in the posture analysed for Task 3.

The six boundary cases, grouped in female and male cases, are shown in Fig. 29.
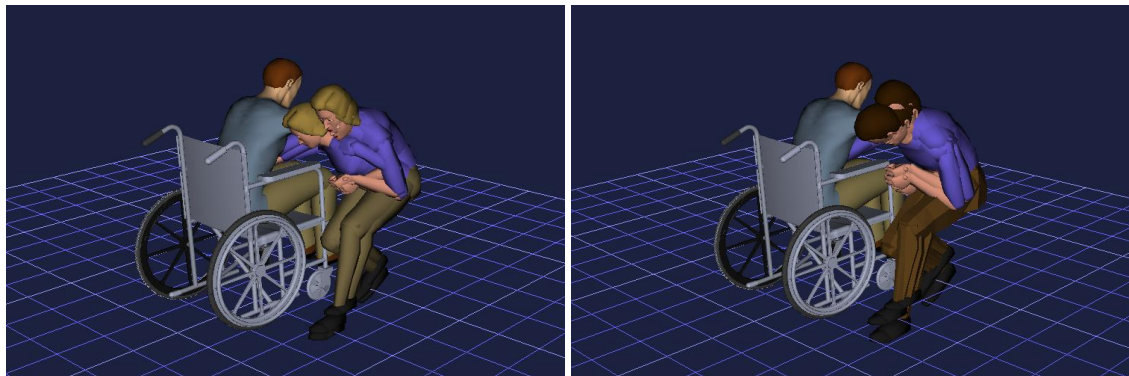
Fig. 29. Female (left) and male (right) manikins in the posture analysed for Task 3.

In Table 17, the results of the evaluation of Task 3, using RULA and OWAS in Jack.

Table 17. Task 3. Evaluation results through RULA and OWAS using Jack.

Case	Task 3	
	Method	
	RULA	**OWAS**
p1	7	2143
p2	7	2143
f1	7	4143
f2	7	2143
f3	7	2143
m4	7	2143
m5	7	2143
m6	7	2143

5.2.1.4 Task 4

In Fig. 30, personas 1 and 2 in the posture analysed for Task 4, are shown.
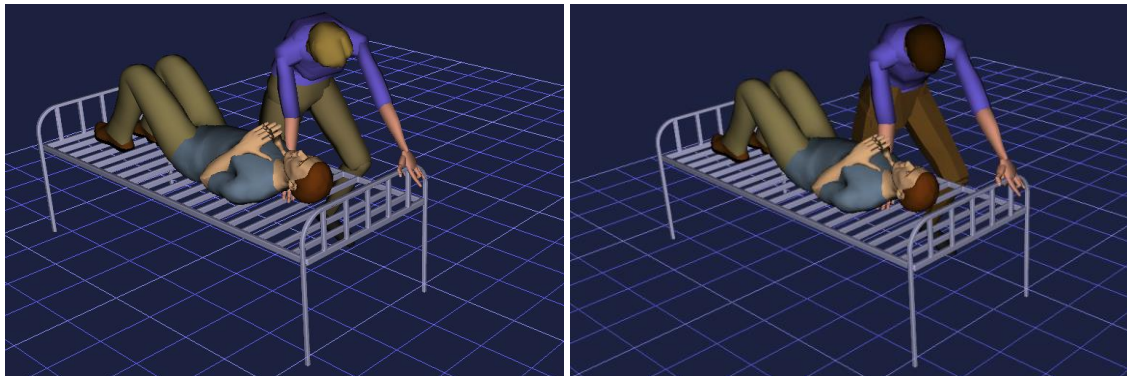
Fig. 30. Personas 1 (left) and 2 (right) in the posture analysed for Task 4.

The six boundary cases, grouped in female and male cases, are shown in Fig. 31.
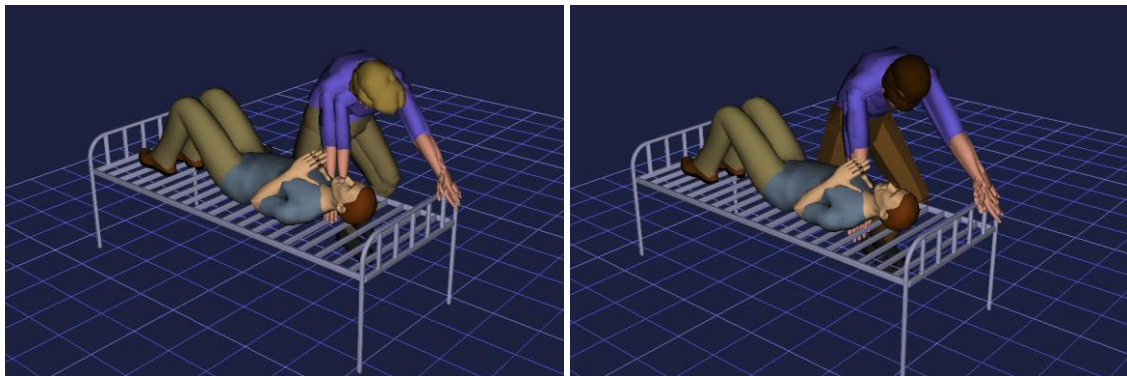
Fig. 31. Female (left) and male (right) manikins in the posture analysed for Task 4.

In Table 18, the results of the evaluation of Task 4, using RULA and OWAS in Jack.

Table 18. Task 4. Evaluation results through RULA and OWAS using Jack.

Task 4		
Case	**Method**	
	RULA	**OWAS**
p1	7	4152
p2	7	4152
f1	7	4152
f2	7	4152
f3	7	4152
m4	7	4152
m5	7	4152
m6	7	4152

5.2.2 Surgeons' tasks

In the case of the surgeons' tasks, critical postures have been analysed for the subject based on Persona 3. The methods used are OWAS and RULA.

5.2.2.1 Task 5

Fig. 32 shows the surgeon (persona 3), in the critical posture analysed for Task 5.
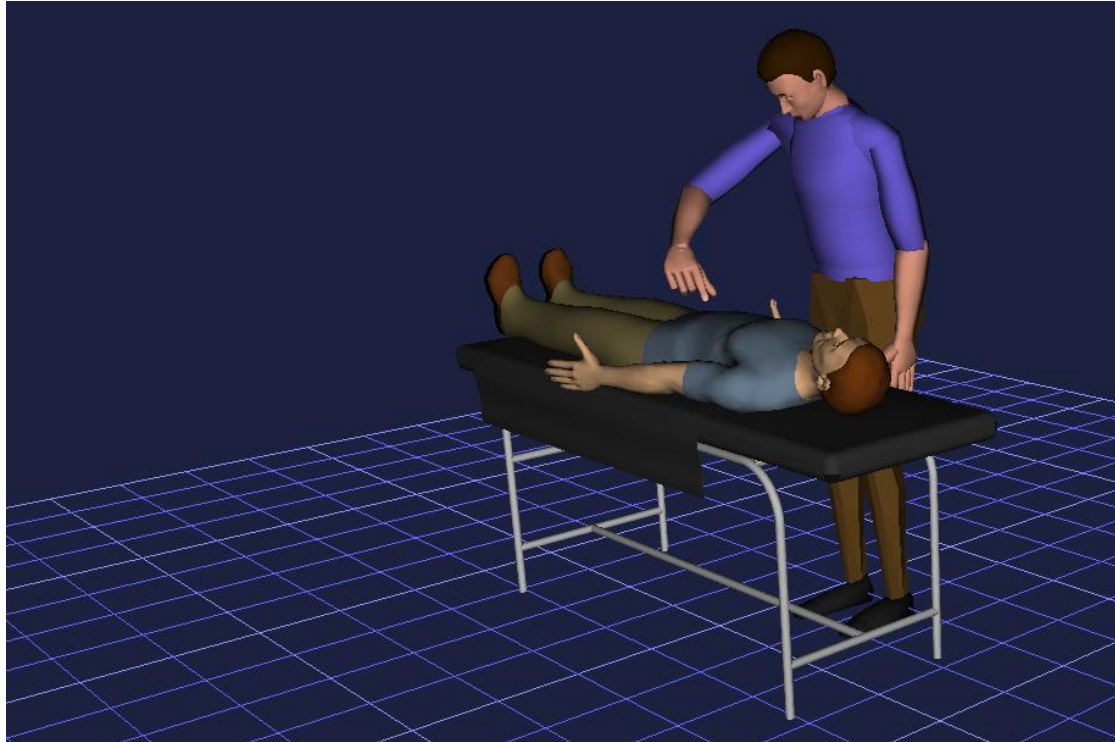
Fig. 32. Surgeon in the posture analysed for Task 5.

In Table 19, the results of the evaluation of Task 5, using RULA and OWAS in Jack.

Table 19. Task 5. Evaluation results through RULA and OWAS using Jack.

Task 5		
Case	**Method**	
	RULA	**OWAS**
p3	5	2121

5.2.2.2   Task 6

Fig. 33 shows the surgeon (persona 3), in the critical posture analysed for Task 6.
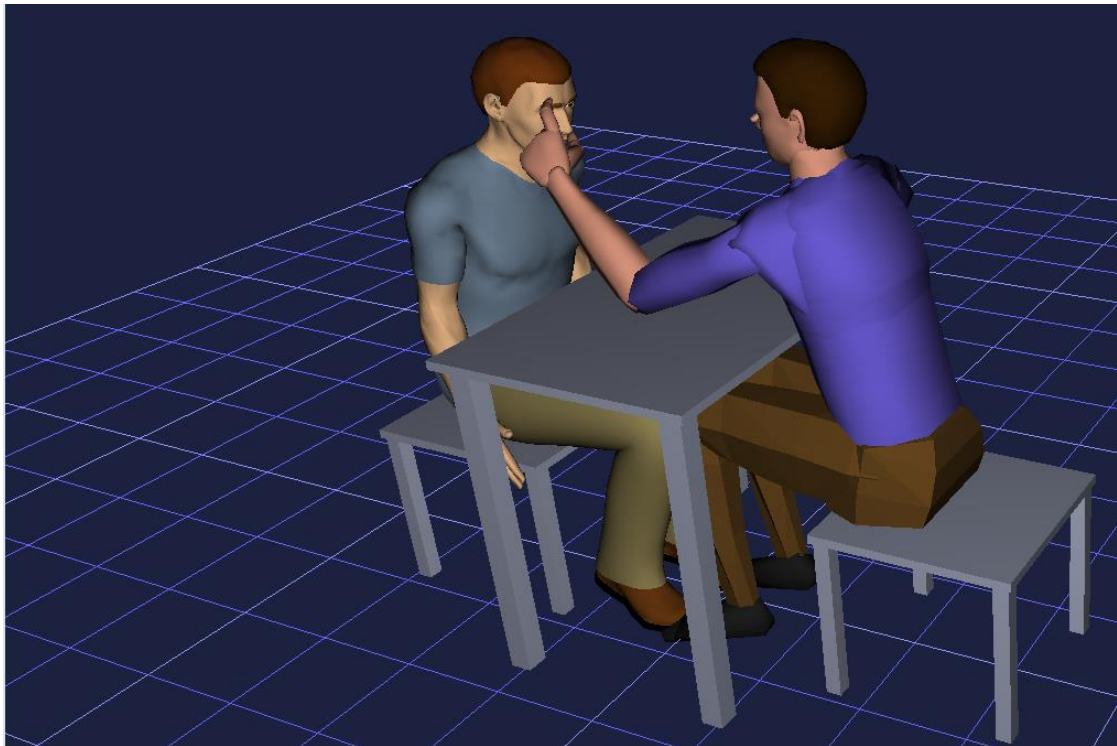
Fig. 33. Surgeon in the posture analysed for Task 6.

In Table 20, the results of the evaluation of Task 6, using RULA and OWAS in Jack.

Table 20. Task 6. Evaluation results through RULA and OWAS using Jack.

Task 6		
Case	**Method**	
	RULA	**OWAS**
p3	3	2341

5.3 RULA RESULTS: A COMPARISON BETWEEN MOTION CAPTURE AND DHM

To discuss the differences between motion capture and manual modelling, the scores returned by the RULA evaluation method using each of these inputs is shown in Table 21. A third column indicating the variation in the results for each task and persona has been added. This is the first step to know the consistency of the results obtained when using manual modelled manikins or motion capture files as input, and the previous step to know the reasons behind the differences between each approach.

Table 21. RULA evaluation method scores using two evaluation techniques.

| Task | Persona | Technique | | Motion capture variation regarding DHM |
		RULA via Motion Capture	RULA via Manually modelled manikins	
Task 1	p1	4	6	-2
	p2	7	6	+1
Task 2	p1	-	7	—
	p2	7	7	0
Task 3	p1	-	7	—
	p2	7	7	0
Task 4	p1	7	7	0
	p2	6	7	-1
Task 5	p3	3	5	-2
Task 6	p3	-	3	—

5.4 RESULTS OF PERSONAS

In the three following sections, the evaluation results appear classified under each persona.

5.4.1 Persona 1

Results of the evaluations of persona 1 are collected in Table 22.

Table 22. Overall evaluation results for Persona 1.

| Task | Persona 1 | | |
| | Motion Capture | Manually modelled manikins | |
	RULA	RULA	OWAS
Task 1	4	6	2141
Task 2	-	7	2142
Task 3	-	7	2143
Task 4	7	7	4152

5.4.2 Persona 2

Results of the evaluations of persona 1 are collected in Table 23.

Table 23. Overall evaluation results for Persona 2.

Persona 2			
Task	**Motion Capture**	**Manually modelled manikins**	
	RULA	RULA	OWAS
Task 1	7	6	2141
Task 2	7	7	2142
Task 3	7	7	2143
Task 4	6	7	4152

5.4.3 Persona 3

Results of the evaluation of persona 1 are collected in Table 24.

Table 24. Overall evaluation results for Persona 3.

Persona 3			
Task	**Motion Capture**	**Manually modelled manikins**	
	RULA	RULA	OWAS
Task 5	3	5	2121
Task 6	-	3	2341

6 CONCLUSIONS

This project finds its foundation on the use of ergonomic evaluation techniques such as self-reports, observational techniques, and direct measurement methods for the assessment of work conditions in the healthcare industry. The three of them have been somehow applied during the development of the project.

Self-reports, embodied as interviews and questionnaires, have resulted to be especially useful research tools. Insight and experiences shared by the group of study helped to shape the problem and deepen its understanding, as well as defining the path of the study. The application of advanced observational techniques and direct measurement methods have encompassed the technical side of this project. Motion capture system showed to be more difficult to implement than DHM tools, however, once technical hurdles were overcome, its simplicity and time-saving attributes stood out. On the other hand, results from using motion capture files or manually modelled manikins as input have been quite similar. However, manually modelling of manikins have demonstrated to represent the study cases more accurately and reliably in this specific project, as will be explained in section 7. Discussion.

Taking a closer look at the results obtained using motion capture systems and IPS IMMA for ergonomic evaluation, they do not seem completely accurate. Three out of the ten tasks (tasks two and three performed by persona 1) were not correctly processed, the representation of other two seems dubious (task 1 performed by persona 2 and task 4 by persona 1) and the remaining five are just correct. This can be explained considering that IPS IMMA is a software that is still under development and some of the features included are not completely defined so, despite everything, the obtained results are reasonably correct. It can be concluded that motion capture technologies could be in the future a great tool to represent real human postures and evaluate them in terms of ergonomics, once those technical issues are overcome. For the moment, motion capture technologies—or at least, the conjunction of Xsens and IPS IMMA used in this research—only can represent humans digitally with a certain level of reliability.

On the other hand, RULA results are not exactly the same when using manual manikin modelling or motion capture files as input. Out of the seven tasks that can be taken into account (excluding tasks 2 and 3 by persona 1), results differ as follows (see Table 21):

- 3/7 results are equal.
- 4/7 results vary 1 or 2 points up or down.

For tasks 1 to 4 (nurses' tasks), both RULA and OWAS evaluation methods inform the need for an 'immediate' or 'as soon as possible' change, which is not surprising thinking about the demands in force and posture. On the other hand, warnings for tasks 5 and 6 (surgeons' tasks) vary from one evaluation method to the other.

Concurrently, OWAS method has been also applied to the nurses' tasks: comparing to RULA, OWAS' evaluations have been slightly more optimistic. For instance, warning messages in tasks 2 and 3 when analysing them using OWAS were 'action as soon as possible' (orange colour), while the warning messages given by RULA for the same tasks were 'investigate and change immediately' (red colour). Taking a closer look to the OWAS' coding, it can be seen that if 'both arms [are] below shoulder', it is not possible to obtain a 'class 4 risk'—i.e. a warning message that recommends 'immediate

action' (red colour)— unless knees were bent, which was not the case. As can be seen, little differencies in the methodology that each evaluation method follows, can lead to more different warning messages. This indicates, once again, that results provided by available evaluation methods should be considered with caution.

Considering anthropometric diversity was also a major part of the project. The use of personas and motion capture systems can be very valuable since the simulation and the evaluation are focused on one person at a time. Hence, results can be highly reliable. The problem is that the study of a specific person does not represent the whole population. To extend the results and make them valid for more people, some method or tool is needed. The creation of a family of six manikins to consider anthropometric diversity was included for this purpose in section 5.2. However, just in one task (task 3, see Table 17), there was a different result for one of the six personas. The rest of the tasks presented the same result for each of the family manikins. The reason for that could be that, if the postures evaluated are already hazardous for the personas studied—whose anthropometric percentiles are closer to the arithmetic mean— understandably, those postures are equally hazardous for the boundary cases represented within the family of manikins. And, since loads and weights involved are the same in the case of the personas and of the family's manikins, scores could not be higher than what they already are. Although results were the same in 47 out of 48 cases evaluated, it is still important to consider that diversity in ergonomic studies, and this would not be possible using motion capture systems unless the studied population were great. Having considered the anthropometric diversity, it is possible to state that both the personas and the manikins of the families are in risk performing the studied tasks; but this statement could have not been done without considering the anthropometric diversity.

Summarizing, all the tasks have turned out to be potentially harmful. Results from using motion capture files or manually modelled manikins as imput, although different, agreed in most cases that some type of intervention was necessary 'immediately' or 'soon'.

7 DISCUSSION

From the results, it can be ensured that patient handling techniques, although performed following the established protocols, suppose a high risk for musculoskeletal disorders in nurses and must be redefined in order to lower the potential risk of each one of them. Surgeons' conditions, in contrast, seem more difficult to assess through ergonomic tools due to the variety of 'subjective' factors that must be considered—e.g. concentration, precision or pressure due to time or difficulty of the surgical intervention—. In addition, the ergonomic evaluation methods consider the duration of the tasks by framing them in various ranges. This fact origins limitations in the study of static postures. For instance, RULA would return the same value for a static posture maintained for ten or twenty minutes.

Work pressure is also a factor that could affect nurses. According to some studies (Burton et al., 1997), nurses´ perception of workload being the cause of their symptoms of musculoskeletal disorders is common. The interviewed nurses for this project (see appendix) also considered that work pressure was a handicap when they had to adjust hospital equipment to their dimensions. Nurses argued that having a great number of patients to be treated in a short period of time hampered them to regulate bed height when lifting and transferring patients, for example. Other nurse stated that his primary health centre does not have adjustable height beds at its disposal. "The use of adjustable beds in nursing practice could influence the working postures of nursing personnel and lead to a reduction in task demands." (Caboor et al., 2000)

While the surgeons' tasks do not comprise any added weight, for the nurses it is difficult to estimate the loads and forces they support in each task. Even though a biomechanical study should be carried out to correctly define these variables, an approximation for each task has been made, as shown in section 4.6.1. In Jack Tecnomatix, RULA and OWAS methods get the load definition in different ways: in RULA, weight is selected from the four specific ranges considered in the method, whereas OWAS needs for the weight to be previously applied to the manikin in specific regions of the body. Due to the difficulty of assessing which parts of the body carry the load during the tasks and hence define the last digit in the OWAS resulting code, the scores have been adjusted afterwards according to the three ranges defined in the original OWAS method, while the first three digits resulting directly from the simulation have been kept.

As mentioned in the previous section, the manual modelling of manikins have demonstrated to represent the study cases more accurately and reliably in this project. What leads to this conclusion is that in some tasks (task 1 by persona 2, task 4 by persona 1 and task 6 by persona 3), the location of certain parts of the body have not been correctly interpreted by IPS IMMA (see Fig. 15, Fig. 20 and Fig. 23, respectively). Given this disagreement between the manikins' postures in IPS IMMA and the ones modelled manually in Jack Tecnomatix it must be said that, for instance, a bad translation of an angle or of the location of a joint between Xsens MVN Analyze and IPS IMMA, can highly vary the result. Looking at the pictures taken during the recording session, and comparing the real postures to those represented by manikins in IPS IMMA and Jack, it is clear that the manikins modelled manually—although are neither completely exact, since are modelled trying to represent postures by observing pictures, and there is always the possibility of the human error—are closer to the reality than the manikins created by IPS IMMA from the motion capture files. Hence, results obtained through Jack Tecnomatix can be considered more realistic.

Given the limitations of both DHM software—such as the wrong reading of motion capture files in the case of IPS IMMA or inaccuracy when modelling manikins manually in Jack Tecnomatix—and available methods—such as time and load definition in ranges, instead of an exact definition—, it is important to be aware that evaluation results using these tools and procedures are just warnings which should be considered, analysed and used to start a deeper investigation, if necessary.

Interviews with nurses and surgeons constituted an important part of the research since they were—along with manuals, books and multimedia resources—the sources used to select the tasks to simulate. The original plan was to have one-to-one interviews with workers from the Skaraborg Sjukhus of Skövde, as many as possible. However, the COVID-19 made this unfeasible. Looking for alternatives, it was finally possible to set up six telephonic interviews, three with nurses and three with surgeons. Interviewees also agreed to fill out a questionnaire that was sent to them by email. This was a satisfactory solution and helped to identify the specific problems that nurses and surgeons go through during their work. However, this alternative solution also brought two problems:

- The first problem is that interviewees were from Spain—due to our nationality, Spaniards were much easier to contact considering the COVID-19 situation—, while this research was being carried out in Sweden. Database for anthropometric diversity (Hanson et al., 2009) includes Swedish individuals; and the interview with the Health Department of the University of Skövde also assumed that the work conditions studied were the work conditions of Swedish nurses and surgeons. Although the health care systems of both countries may be similar, it would have been better if all the study had been developed considering just one country.
- The second problem is that it was only possible to contact six different people. The six interviews were extremely useful to select the tasks to simulate, but it is obvious that more interviews could have improved the reliability of the study.

On the other hand, although the interviews were designed to have open questions, the need to obtain answers to specific questions may have led to the construction of not so open questions. Probably, some of them could be improved. For instance, at the end of the interview, there are three questions regarding 'previously identified problems'. The objective here was to confirm or reject the importance of those problems, but questions could have been designed surrounding the topic, so that the interviewee could talk or not about those problems (and so confirm or reject that importance), better than specifically ask him or her if they had ever experienced those particular issues.

8 FUTURE WORK

Below, some proposals related to the topic of this project are described:

- Development of a biomechanical study of the most hazardous postures according to the results obtained.
- Improvement of compatibility between IPS IMMA and Xsens files, so that motion capture can be correctly interpreted by IPS IMMA.
- Development of a community or forum for IPS IMMA issues that cannot be easily solved reading the IPS User Manual.
- Development of healthcare equipment that can be adjusted faster. One of the complaints of nurses was that beds adjustment or the use of medical cranes require a time they cannot spend on many occasions.
- Development of advising programmes on postural care for surgeons. Whereas the interviewed nurses stated that they had received training in subjects like patient handling techniques, for example, surgeons had not received formation in issues related to postural care.
- Age suits, composed by a set of pieces attached to the body, restrict the range of motion of the user trying to imitate the physical limitations of the elder people. The Health Care Department of the University of Skövde has age suits with a number of interchangeable pieces. However, the correlation between the imposed restriction of the age suits and the real restrictions experienced by old people is still to be determined. Using motion capture technologies like Xsens to check the age suits' reliability could constitute an interesting and useful study.
- Evaluation through methods other than the used in this research, such as REBA to better consider legs implication; or the Strain Index, to assess hands and lower arms risk exposure, which could be especially useful for surgeons.

9 REFERENCES

American Journal of Nursing, 1979. How much time do nurses spend doing direct patient care: AJN, American Journal of Nursing 79, 1753–1756. https://doi.org/10.1097/00000446-197910000-00036

Antolinos Guinart, J.I., 2016. Movilización de personas con movilidad reducida: consultas técnicas frecuentes. ¿Qué método se debe utilizar para la evaluación de los riesgos en tareas de movilización de personas con movilidad reducida? FREMAP.

Arvidsson, I., Gremark Simonsen, J., Dahlqvist, C., Axmon, A., Karlson, B., Björk, J., Nordander, C., 2016. Cross-sectional associations between occupational factors and musculoskeletal pain in women teachers, nurses and sonographers. BMC Musculoskelet Disord 17, 35. https://doi.org/10.1186/s12891-016-0883-4

Aust, B., Rugulies, R., Skakon, J., Scherzer, T., Jensen, C., 2007. Psychosocial work environment of hospital workers: Validation of a comprehensive assessment scale. International Journal of Nursing Studies 44, 814–825. https://doi.org/10.1016/j.ijnurstu.2006.01.008

Bertilsson, E., Svensson, E., Högberg, D., Hanson, L., 2010. Use of digital human modelling and consideration of anthropometric diversity in Swedish industry. Presented at the 42nd annual Nordic Ergonomic Society Conference.

Bos, E., Krol, B., van der Star, L., Groothoff, J., 2007. Risk factors and musculoskeletal complaints in non-specialized nurses, IC nurses, operation room nurses, and X-ray technologists. International Archives of Occupational and Environmental Health 80, 198–206. https://doi.org/10.1007/s00420-006-0121-8

Brolin, E., Högberg, D., 2019. Physical Ergonomics Assessment Methods. University of Skövde.

Brolin, E., Högberg, D., Hanson, L., 2012. Description of boundary case methodology for anthropometric diversity consideration. IJHFMS 3, 204. https://doi.org/10.1504/IJHFMS.2012.051097

Burton, A.K., Symonds, T.L., Zinzen, E., Tillotson, K.M., Caboor, D., Van Roy, P., Clarys, J.P., 1997. Is ergonomic intervention alone sufficient to limit musculoskeletal problems in nurses? Occup Med 47, 25–32. https://doi.org/10.1093/occmed/47.1.25

Caboor, D.E., Verlinden, M.O., Zinzen, E., Van Roy, P., Van Riel, M.P., Clarys, J.P., 2000. Implications of an adjustable bed height during standard nursing tasks on spinal motion, perceived exertion and muscular activity. Ergonomics 43, 1771–1780. https://doi.org/10.1080/001401300750004177

Chapanis, A., 1995. Ergonomics in product development: a personal view. Ergonomics 38, 1625–1638. https://doi.org/10.1080/00140139508925214

Daraiseh, N., Genaidy, A.M., Karwowski, W., Davis, L.S., Stambough, J., Huston, R.L., 2003. Musculoskeletal outcomes in multiple body regions and work effects among nurses: the

effects of stressful and stimulating working conditions. Ergonomics 46, 1178–1199. https://doi.org/10.1080/0014013031000139509

David, G.C., 2005. Ergonomic methods for assessing exposure to risk factors for work-related musculoskeletal disorders. Occup Med (Lond) 55, 190–199. https://doi.org/10.1093/occmed/kqi082

Duffy, V.G., Chaffin, D.B., Wang, X., 2008. Handbook of Digital Human Modelling: Research for Applied Ergonomics and Human Factors Engineering, Human Factors and Ergonomics. CRC Press.

Engels et al., n.d. An OWAS-based analysis of nurses' working postures. https://doi.org/10.1080/00140139408963700

Grooten, W., Johansson, E., 2018. Observational Methods for Assessing Ergonomic Risks for Work-Related Musculoskeletal Disorders. A Scoping Review. Revista Ciencias de la Salud 16, 8. https://doi.org/10.12804/revistas.urosario.edu.co/revsalud/a.6840

Hanson, G.-Å., Balogh, I., Byström, J.U., Ohlsson, K., Nordander, C., Asterland, P., Sjölander, S., Rylander, L., Winkel, J., Skerfving, S., Malmo Shoulder-Neck Study Group, 2001. Questionnaire versus direct technical measurements in assessing postures and movements of the head, upper back, arms and hands on JSTOR. Scandinavian Journal of Work, Environment & Health 27, 30–40.

Hanson, L., Sperling, L., Gard, G., Ipsen, S., Olivares Vergara, C., 2009. Swedish anthropometrics for product and workplace design. Applied Ergonomics 40, 797–806. https://doi.org/10.1016/j.apergo.2008.08.007

Hignett, S., McAtamney, L., 2000. Rapid Entire Body Assessment (REBA). Applied Ergonomics 31, 201–205. https://doi.org/10.1016/S0003-6870(99)00039-3

Hollmann, S., Klimmer, F., Schmidt, K.-H., Kylian, H., 1999. Validation of a questionnaire for assessing physical work load. Scandinavian Journal of Work, Environment & Health 25(2), 105–114.

Homan, M.M., Armstrong, T.J., 2003. Evaluation of Three Methodologies for Assessing Work Activity During Computer Use. AIHA Journal 64, 48–55. https://doi.org/10.1080/15428110308984784

Janowitz, I.L., Gillen, M., Ryan, G., Rempel, D., Trupin, L., Swig, L., Mullen, K., Rugulies, R., Blanc, P.D., 2006. Measuring the physical demands of work in hospital settings: Design and implementation of an ergonomics assessment. Applied Ergonomics 37, 641–658. https://doi.org/10.1016/j.apergo.2005.08.004

Jansson, C., Alexanderson, K., 2013. Sickness absence due to musculoskeletal diagnoses and risk of diagnosis-specific disability pension: A nationwide Swedish prospective cohort study: Pain 154, 933–941. https://doi.org/10.1016/j.pain.2013.03.001

Karhu, O., Kansi, P., Kuorinka, I., 1977. Correcting working postures in industry: A practical method for analysis. Applied Ergonomics 8, 199–201. https://doi.org/10.1016/0003-6870(77)90164-8

Kee, D., Karwowski, W., 2001. LUBA: an assessment technique for postural loading on the upper body based on joint motion discomfort and maximum holding time. Applied ergonomics 32, 357–366.

Kemmlert, K., 1995. A method assigned for the identification of ergonomic hazards—PLIBEL. Applied Ergonomics 26, 199–211.

Kuorinka, I., Jonsson, B., Kilbom, A., Vinterberg, H., Biering-Sørensen, F., Andersson, G., Jørgensen, K., 1987. Standardised Nordic questionnaires for the analysis of musculoskeletal symptoms. Appl Ergon 18, 233–237. https://doi.org/10.1016/0003-6870(87)90010-x

Letvak, S.A., Ruhm, C.J., Gupta, S.N., 2012. Nurses' presenteeism and its effects on self-reported quality of care and costs. Am J Nurs 112, 30–38; quiz 48, 39. https://doi.org/10.1097/01.NAJ.0000411176.15696.f9

Li, G., Buckle, P., 2016. Evaluating Change in Exposure to Risk for Musculoskeletal Disorders — A Practical Tool: Proceedings of the Human Factors and Ergonomics Society Annual Meeting. https://doi.org/10.1177/154193120004403001

Loosveldt, G., Beullens, K., 2013. "How long will it take?" An analysis of interview length in the fifth round of the European Social Survey. Survey Research Methods 7, 69–78. https://doi.org/10.18148/srm/2013.v7i2.5086

Lowe, B.D., Dempsey, P.G., Jones, E.M., 2019. Ergonomics assessment methods used by ergonomics professionals. Applied Ergonomics 81, 102882. https://doi.org/10.1016/j.apergo.2019.102882

Martínez Fernández, S., 2009. Manual de movilización de pacientes. Servicio Prevención Riesgos Laborales de Palencia.

McAtamney, L., Nigel Corlett, E., 1993. RULA: a survey method for the investigation of work-related upper limb disorders. Applied Ergonomics 24, 91–99. https://doi.org/10.1016/0003-6870(93)90080-S

Menzel, N.N., Brooks, S.M., Bernard, T.E., Nelson, A., 2004. The physical workload of nursing personnel: association with musculoskeletal discomfort. International Journal of Nursing Studies 41, 859–867. https://doi.org/10.1016/j.ijnurstu.2004.03.012

Moore, J.S., Garg, A., 1995. The Strain Index: A Proposed Method to Analyze Jobs For Risk of Distal Upper Extremity Disorders. American Industrial Hygiene Association Journal 56, 443–458. https://doi.org/10.1080/15428119591016863

Nelson, A., Motacki, M.K., Menzel, D.N., 2009. The Illustrated Guide to Safe Patient Handling and Movement. Springer Publishing Company.

Nielsen, L., 2019. Personas - User Focused Design, Second. ed, Human–Computer Interaction Series. Springer London, London.

Occhipinti, E., 1998. OCRA: a concise index for the assessment of exposure to repetitive movements of the upper limbs. Ergonomics 41, 1290–1311. https://doi.org/10.1080/001401398186315

Preece, J., Rogers, Y., Sharp, H., 2002. Interaction design : beyond human-computer interaction. J. Wiley & Sons, Year: 2002.

Richter, M., Flückiger, M., 2014. User-Centred Engineering: Creating Products for Humans, 1st ed. Springer-Verlag Berlin Heidelberg.

Rugulies, R., Braff, J., Frank, J.W., Aust, B., Gillen, M., Yen, I.H., Bhatia, R., Ames, G., Gordon, D.R., Janowitz, I., Oman, D., Jacobs, B.P., Blanc, P., 2004. The psychosocial work environment and musculoskeletal disorders: Design of a comprehensive interviewer-administered questionnaire. Am. J. Ind. Med. 45, 428–439. https://doi.org/10.1002/ajim.20009

Snook, S.H., Ciriello, V.M., 1991. The design of manual handling tasks: revised tables of maximum acceptable weights and forces. Ergonomics 34, 1197–1213. https://doi.org/10.1080/00140139108964855

Soylar, P., Ozer, A., 2018. Evaluation of the prevalence of musculoskeletal disorders in nurses: A systematic review. Medicine Science 7, 1. https://doi.org/10.5455/medscience.2017.06.8747

Spath, D., Braun, M., Hagenmeyer, L., 2006. Human Factors and Ergonomics in Manufacturing and Process Control, in: Handbook of Human Factors and Ergonomics. John Wiley & Sons, Inc., New Jersey, p. 1662.

Spielholz, P., Silverstein, B., Morgan, M., Checkoway, H., Kaufman, J., 2001. Comparison of self-report, video observation and direct measurement methods for upper extremity musculoskeletal disorder physical risk factors. Ergonomics 44, 588–613. https://doi.org/10.1080/00140130118050

Taveira, Á.D., Smith, M.J., 2006. Social and Organizational Foundations of Ergonomics, in: Salvendy, G. (Ed.), Handbook of Human Factors and Ergonomics. Springer, pp. 269–291.

Unruh, G.U., Canciglieri Junior, O., 2018. Human and User-Centered Design Product Development: A Literature Review and Reflections. Transdisciplinary Engineering Methods for Social Innovation of Industry 4.0 211–220. https://doi.org/10.3233/978-1-61499-898-3-211

US Department of Labor Bureau of Labor Statistics, 2002. Nonfatal occupational injuries and illnesses: number of cases and incidence rates for private industries with 100,000 or more total cases, 2001.

Vereczkei, A., Feussner, H., Negele, T., Fritzsche, F., Seitz, T., Bubb, H., Horváth, Ö.P., 2004. Ergonomic assessment of the static stress confronted by surgeons during laparoscopic cholecystectomy. Surg Endosc 18. https://doi.org/10.1007/s00464-003-9157-y

Waters, T.R., Nelson, A., Hughes, N., Menzel, N., 2009. Safe Patient Handling Training for Schools of Nursing: Curricular materials. DHHS (NIOSH).

Waters, T.R., PUTZ-ANDERSON, V., GARG, A., FINE, L.J., 1993. Revised NIOSH equation for the design and evaluation of manual lifting tasks. Ergonomics 36, 749–776. https://doi.org/10.1080/00140139308967940

Xsens Technologies B.V., 2018. MTw Awinda User Manual.

Yan, P., Li, F.Y., Wang, Y.N., Huang, A.M., Yao, H., 2016. Current status of work-related musculoskeletal disorders in nurses in Xinjiang, China. Chinese journal of industrial hygiene and occupational diseases 34, 561–565. https://doi.org/10.3760/cma.j.issn.1001-9391.2016.08.001

10 APPENDIX

10.1 INTERVIEWS AND QUESTIONNAIRES WITH NURSES AND SURGEONS

10.1.1 Interviews with nurses

<div align="center">

INTERVIEW WITH NURSES: SUBJECT A

</div>

Demographic data

Identification (A, B, C, etc.)	A
Age	24
Gender	Female
Weight (kg)	44 kg
Height (cm)	160 cm
Sitting acromial (cm)	55 cm
Acromial height (cm)	125 cm
Shift duration (h)	12 hours
Active years	3 years
Speciality	Oncology
Centre	General Hospital Doctor José Medina

Questions

Subjective vision

- Do you think you have had pain due to work? Where? Which tasks do you think influence that pain?

  Yes, I have had pain due to work. It's hard to clean people and change medication through the catheter. Normally, the catheter is located in the forearm, but sometimes is in other parts (near clavicle or groin, for example).

  When it comes to bath the patient, this is theorically a task of the nurse assistant, but nurses have to do it also very often. The washing can take place in the bathroom or even in the bed, if the patient cannot move by him or herself. Both cases can be equally hard. In the first case, the patient maybe can wash the upper body by him or herself, but we have to wash the lower body, normally taking a bad posture, sometimes on our knees. If the patient cannot get out of bed is, normally, because he or she has injured some part of the body (broken bones, burns) and, in this case, washings can last up to three times a normal washing, because you have to be extra-careful.

- Is there any posture that you consider to be especially tough? Which? In which context?

  Yes. Apart from changing medication and washing patients, those which imply moving the patient: transfers. For example, from bed to chair, from one chair to another (normally from wheelchair to a normal chair, or the opposite)

or taking patients up on bed (pushing them up to the headboard, because they have been sliding down bed) .

- Is there any task that you consider especially uncomfortable?

Yes. Changing medication. When you have been working for several hours, you end up with a pain in the lower back. Not so much at the beginning of the day. The thing is that the patient is, for example, lying down on bed. Normally, you have to lower the bed so that there is no falling risk for the patient. It depends on where he or she has the catheter, but you can take very weird postures, since you have to do all the work and there is no possible collaboration on his or her part.

Taking patients up on bed is also very hard. There are techniques, but they are not normally followed rigorously. Sometimes, the patient holds on you, harming you.

Cleaning the lower limbs of the patients can imply very uncomfortable postures, too.

Psychosocial aspects

- Do you consider that time-related work pressure makes an impact on the quality of your postures? In which sense?

I think that is the most important cause, the main reason. We know what we have to do, I know the techniques. But there are many situations, when you are running against the clock… You do not stop to adjust the bed's height, or to take better postures.
- Do you feel like the quality of your postures varies during your workday?

Yes, of course. At the beginning you are more aware, and more rested.

Intensity, duration & frequency

- Which are the most time-consuming tasks?

The washing, especially with those confined to bed.
- Which are the most physically demanding tasks?

I would say that two different kind of transfers: transfer from bed to chair and taking up on the bed.

- Which are the most repeated tasks?

Changing medication and taking patients up on the bed.

Previously identified problems

- Have you ever had postural problems while...
  - cleaning patients with reduced mobility?

    Yes. As I explained before.
  - changing patients from one bed to another or to a chair?

    Yes, the same. This is what we refer as transfers.
  - carrying patients in wheelchairs?

    Not so much.

Improvements

- Any improvements?

Well… We know that we are not taking good postures sometimes, but is the lack of time which leads us to not care our postures.

Demographic data

Identification (A, B, C, etc.)	B
Age	26
Gender	Male
Weight (kg)	90
Height (cm)	176
Sitting acromial (cm)	60
Acromial height (cm)	144
Shift duration (h)	7 hours
Active years	3 years
Speciality	Primary health care
Centre	Primary Health Care Centre Puerto del Carmen

Questions

Subjective vision

- Do you think you have had pain due to work? Where? Which tasks do you think influence that pain?

   Yes, I have. Mainly in the lower back. About the tasks... Doing some treatments or some cures. Some cures last 2 minutes, but others can last even more than one hour. Some analyses are also hard, because there are not adjustable tables. We do not have electronic beds. Beds have a fixed height. There is only a hydraulic one.

- Is there any posture that you consider to be especially tough? Which? In which context?

   Yes, when I do some transfers... the posture can be very uncomfortable, and we do not have equipment for that. Sometimes we go to the patient's home, and there... you have to adapt yourself to the environment, and we maybe have to stand on our knees. It is difficult.

- Is there any task that you consider especially uncomfortable?

   Yes. For example, sometimes we have to extend our bodies through the bed, so that the patient does not need to move. We do this to change the catheter, to do some analytical tests or controls. In home care visits, with patients with reduced mobility... sometimes I have to be lying on the floor, or squatted.

Psychosocial aspects

- Do you consider that time-related work pressure makes an impact on the quality of your postures? In which sense?

   Yes, of course. Always. At the centre where I work... we are in the middle of a touristic place. I have been attending 53 patients in one morning, with more than 20 cures or treatments. That day I was working in three different consulting rooms. When you are working in such a say, you do not have time to worry about you, to take care of your health, because the patient is always the first.

- Do you feel like the quality of your postures varies during your workday?

It depends on the season, on the time of the year. During the summer season all day is terrific. In more relaxed, calm seasons, yes: at the beginning of the day we are more relaxed, and we can take more care of us.

Intensity, duration & frequency

- Which are the most time-consuming tasks?

Usually what takes the longest are cures. A large suture, a heart attack, may also appear. It depends a little on demand. What is always programmed are the cures. Then whatever comes of urgency.

- Which are the most physically demanding tasks?

People with very reduced mobility. They are people that —this has also happened to me during heart attacks—, people that you have to lift yourself by force.

- Which are the most repeated tasks?

Analytical controls, constant tests and cures.

Previously identified problems

- Have you ever had postural problems while...
  - cleaning patients with reduced mobility?
    Absolutely
  - changing patients from one bed to another or to a chair?
    Absolutely, also. This is one I was talking about before.
  - carrying patients in wheelchairs?
    For me, physically, it does not cause me any problems inside the centre. Outside the centre, with slopes, sidewalks without access for reduced mobility, maybe yes... Cause the asphalt outside the medical centre is all rusted.

Improvements

- Any improvements?

I have already proposed management and improvements: enabling analytical tables, narrower, so that you can do the analytics sitting, without having to get up. I have also proposed the purchase of electric stretchers, at least. In homes... well, there we will have to manage the situations.

We have been told during all our training that we should take care of our postures and stuff. But if there is no material... what? In hospitals the equipment, stretchers are usually electrical, but what about us?

Demographic data

Identification (A, B, C, etc.)	C
Age	24
Gender	Female
Weight (kg)	69
Height (cm)	168
Sitting acromial (cm)	55
Acromial height (cm)	133
Shift duration (h)	12 hours
Active years	3 years
Speciality	Emergency and ordinary consults
Centre	General Hospital Doctor José Medina

Questions

Subjective vision
- Do you think you have had pain due to work? Where? Which tasks do you think influence that pain?

    Daily tasks. For malpractice, in emergencies, especially, when channelling or putting medication. The patients are supine, and the beds are low so that they do not fall. Stretch forward with your back, without flexing your knees... ends up making your lower back hurt. Channelling catheters, medication... are tasks that are very tiring.
- Is there any posture that you consider to be especially tough? Which? In which context?

    Yes, of course. One of the discomforts was working in the operating room for several consecutive hours standing. My lower back and feet ached.

    When doing certain types of cures, also, it depends on the area in which the patient has it, if it has it in the sacrum you have to turn it over. The beds do not go up as much as they should and also have to be lengthened.

    In the operating room on the instrumentation table, in knee replacement or replacement interventions… you have to stand for a long time and often we cannot move because we have to be sterile and we cannot sit.
- Is there any task that you consider especially uncomfortable?

    I think that is when you stretch when changing a catheter.

Psychosocial aspects
- Do you consider that time-related work pressure makes an impact on the quality of your postures? In which sense?

    Yes, totally. In an emergency department you cannot dedicate yourself to adjust the height of the beds if you have to give 15 medications.
- Do you feel like the quality of your postures varies during your workday?

    I guess so. I guess at the beginning of the morning one is more aware. Throughout the day you neglect yourself a little.

- Which are the most time-consuming tasks?

   The cures. They take a long time. Within nursing care is psychological care. The time it takes you to attend to the doubts of the patient or relatives in surgical or post-surgical units ... Many times, they do not ask the doctor and they ask the nurse.

- Which are the most physically demanding tasks?

   Apart from when you have to hold or transfer a patient, which is very demanding... Diabetics: wounds are usually on the feet... You have to bend down, because they are also often obese, older. And in these cases, to do the cures, you have to bend down.

- Which are the most repeated tasks?
   Changing catheters and medication. Arterial blood gases among others.

Previously identified problems

- Have you ever had postural problems while...
   o   cleaning patients with reduced mobility?

      The auxiliaries usually do it, and there are usually two auxiliaries or auxiliary or warden. Ergonomically you have a postural hygiene that you are supposed to carry out, but it is not always possible. Lumbar and shoulders are what suffer the most.

   o   changing patients from one bed to another or to a chair?

      Well, right now, in general, if you have to move a person who has very reduced mobility, they usually use cranes. But above all, arms: lumbar and arms, even you do it well, they suffer.

   o   carrying patients in wheelchairs?

      Yes, although is worse to transfer patients.

Improvements

- Any improvements?

   In terms of resources, I would try to put the controls of the bed that had speeds. If it were faster to get on the bed, we would surely get on the bed faster. I think it is not done for safety, so that the patient does not give it.

   I think for each unit there should be a type of bed. In the emergency department, the patient's entrance, yes or yes, they will have to channel a pathway. They are all invasive techniques. Make a vertical probe ...

   In an operating room, for example, there is an operating table: the legs are removed, the arms are put on, etc. It can be modified, depending on what you are going to do. The needs are not the same in each unit. But above all, the beds and armchairs in which it is served.

   In trauma, for example, they are people who almost always have a fracture. They go to the operating room and, when they return, they come in plaster or with the Balkan beds. I don't think that in the 21st century there is not a way to be able to put a hanging leg. But, a trauma patient after an operation ... the bath is torture.

   Also ... on a delivery table ... There are wonderful delivery beds and then there are others that are the ones that are in most public centres.

10.1.2 Questionnaires with nurses

	Posture	Never	Seldom	Sometimes	Often	Very often
Trunk Posture						
	Straight upright			x		
	Bent half-way forward (about 45º)					x
	Bent very forward (about 75º)				x	
	Twisted/rotated				x	
	Bent to the side			x		
Arm position						
	Both arms raised so that elbows are above chin height				x	
	One arm raised so that elbow is above chin height				x	
	Both arms raised so that elbows are above chest height				x	
	One arm raised so that elbow is above chest height			x		
	Both elbows below chest height				x	
Leg Position						
	Sitting		x			
	Standing					x
	Squatting				x	
	Kneeling (on one or both knees)		x			
	Walking, moving					x
Lifting pushing, pulling or carry with upright trunk posture						
	Light force (up to 11kg)				x	
	Moderate force (11-23 kg)				x	
	Heavy/high force (more than 23 kg)					x
Lifting, pushing, pulling or carry with bent trunk						
	Light weight or force (up to 11 kg)			x		
	Moderate weight or force (11-23 kg)				x	
	Heavy weight or force (more than 23 kg)					x

QUESTIONNAIRE WITH NURSES: SUBJECT B

	Posture	Never	Seldom	Sometimes	Often	Very often
Trunk Posture						
	Straight upright		x			
	Bent half-way forward (about 45º)				x	
	Bent very forward (about 75º)				x	
	Twisted/rotated			x		
	Bent to the side				x	
Arm position						
	Both arms raised so that elbows are above chin height		x			
	One arm raised so that elbow is above chin height		x			
	Both arms raised so that elbows are above chest height			x		
	One arm raised so that elbow is above chest height			x		
	Both elbows below chest height					x
Leg Position						
	Sitting				x	
	Standing				x	
	Squatting				x	
	Kneeling (on one or both knees)				x	
	Walking, moving					x
Lifting pushing, pulling or carry with upright trunk posture						
	Light force (up to 11kg)			x		
	Moderate force (11-23 kg)			x		
	Heavy/high force (more than 23 kg)				x	
Lifting, pushing, pulling or carry with bent trunk						
	Light weight or force (up to 11 kg)			x		
	Moderate weight or force (11-23 kg)				x	
	Heavy weight or force (more than 23 kg)				x	

	Posture	Never	Seldom	Sometimes	Often	Very often
	Trunk Posture					
	Straight upright				x	
	Bent half-way forward (about 45º)					x
	Bent very forward (about 75º)				x	
	Twisted/rotated		x			
	Bent to the side		x			
	Arm position					
	Both arms raised so that elbows are above chin height					x
	One arm raised so that elbow is above chin height					x
	Both arms raised so that elbows are above chest height		x			
	One arm raised so that elbow is above chest height		x			
	Both elbows below chest height					x
	Leg Position					
	Sitting		x			
	Standing					x
	Squatting				x	
	Kneeling (on one or both knees)		x			
	Walking, moving					x
	Lifting pushing, pulling or carry with upright trunk posture					
	Light force (up to 11kg)					x
	Moderate force (11-23 kg)			x		
	Heavy/high force (more than 23 kg)				x	
	Lifting, pushing, pulling or carry with bent trunk					
	Light weight or force (up to 11 kg)					x
	Moderate weight or force (11-23 kg)					x
	Heavy weight or force (more than 23 kg)			x		

10.1.3 Interviews with surgeons

Demographic data

Identification (A, B, C, etc.)	D
Age	36
Gender	Male
Weight (kg)	79
Height (cm)	195
Sitting acromial (cm)	65
Acromion height (cm)	156
Shift duration	6 hours
Active years	12
Speciality	Ophtalmology
Surgery room (specific operations)	Glaucoma and cataract surgery
Centre	Hospiten Roca, Gran Canaria

Questions

Subjective vision
- Do you think you have had pain due to your work as a surgeon? Where?

  Yes, mainly in the back and shoulder areas. In certain situations, this pain can also get to the neck.
- Which parts do you suffer the most during long operations? How many per week?

  Glaucoma surgeries are performed once a week. They last an average of one hour, and after the first thirty minutes, I usually start to experience a pain located in the shoulder and back areas.
- Which parts do you suffer the most during short operations? How many per week?

  Four times per week, cataract surgeries are performed. Since they last just ten minutes and are quite simple, I do not experience any considerable pain. However, if I had to decide, the most affected areas would probably be the neck and lower back.

Intensity, duration & frequency
- How many times do you operate a day? How many times per week?

  One operation per working day. Five operations per week.
- What is the operations' time span?

  Surgery times go from ten minutes up to one hour and a half.
- Which are the most demanding operations? How often do you perform those operations?

  Glaucoma surgeries, because of their duration and need of focus and precision. The postures in this surgery are very static, shoulders' muscles tend to be in tension and trapezius starts to sore.

Individual experience
- Which are the rarest or most uncomfortable postures for the hands (or upper limbs)?

Not a lot of uncomfortable hand postures in surgeries, but in laser sessions. Specifically, when using a system called 'Slit lamp laser' in which, while seated 70 cm away from the patient, I have to maintain mi arm raised and close to the patient's eyes to adjust different lenses. The process can last for twenty minutes.

- Could you describe two postures (in context) that are especially uncomfortable?

    Even though I haven't done it for a while, I remember eyelid and orbit surgery to be specially exhausting. The surgeon works in a stand-up position, gazing downwards and maintaining static postures for long periods of time.

- Could you enumerate the following parts according to the overall soreness experienced? Neck, shoulders, lower back, upper limbs, hands, and legs.

    Back, neck, shoulder, upper limbs, and lower limbs.

- Have you received training related to patient handling (referred to ergonomics) before? Do you apply the principles learned?

    Not that I can remember.

Previously identified problems

- Do you think that there are some external factors that compromise the quality of the ergonomics? Which ones? (surgical instruments, bed's height)

    The equipment is, in average, pretty comfortable to use and very well designed. However, when using microscopes, the neck is a little bit tilted forward and it gets uncomfortable if used for long sessions.

Improvements

- Any potential improvements?

    Not really.

Demographic data

Identification (A, B, C, etc.)	E
Age	27
Gender	Male
Weight (kg)	90
Height (cm)	196
Sitting acromial (cm)	67
Acromion height (cm)	158
Shift duration	8-9 hours
Active years	3
Speciality	Urology
Surgery room (specific operations)	Oncological Urology
Centre	Hospital of La Laguna, Tenerife

Questions

Subjective vision

- Do you think you have had pain due to your work as a surgeon? Where?

    Yes, frequently. Mainly in the back. Ensures that most of the surgeons suffer from lower back pain.

- Which parts do you suffer the most during long operations? How many per week?

    There can be two long operations per week max and these can last up to 8 hours. Pain appears mainly in the neck and back regions (both upper and lower back).

- Which parts do you suffer the most during short operations? How many per week?

    Short operations are considered those that last less than 2 hours. In these cases, pain also appears in the neck and back areas.

Intensity, duration & frequency

- How many times do you operate a day? How many times per week?

    Normally two times per day. It varies depending on the amount of time the operation requires. Only one long surgery per day can be performed and up to three short surgeries per day.

- What is the operations' time span?

    Surgeries span from 2 to 8 hours.

- Which are the most demanding operations? How often do you perform those operations?

    Transplants and laparoscopies. An average of four transplants and eight laparoscopies are performed in a month.

Individual experience

- Which are the rarest or most uncomfortable postures for the hands (or upper limbs)?

    Laparoscopies. These surgeries require high levels of precision and the hands need to be maintained in awkward positions for long periods of time. It usually affects the wrists due to excessive bending which can end up causing

diseases such as carpal tunnel syndrome (CTS). The interviewee ensures that in this specific surgery there is no need of applying high exertions and it is the hand posture that makes it hazardous.

- Could you describe two postures (in context) that are especially uncomfortable?

    Maneuvers implying the separation of tissues or bones, including abdominal wall in kidney operations or the separation of the ribs for liver surgeries. It consists of pulling a tissue or a bone using a long instrument with a bent end, improving the visibility of the other surgeons. There are cases in which the instrument needs to be held for more than 5 minutes straight.

- Could you enumerate the following parts according to the overall soreness experienced? Neck, shoulders, lower back, upper limbs, hands, and legs.

    Lower back, neck, shoulders, hands, arms, and lower limbs.

- Have you received training related to patient handling (referred to ergonomics) before? Do you apply the principles learned?

    Yes, but on a basic level.

Previously identified problems

- Do you think that there are some external factors that compromise the quality of the ergonomics? Which ones? (surgical instruments, bed's height)

    Everything in the surgery room is adjusted for the needs of the main surgeon, however, if they differ a lot from the other members of the team it needs to be discussed and readjusted. The instruments and tools used for the surgeries are all very well 'ergonomically' designed and comfortable. However, they get damaged during sterilization processes affecting this not only to their finishing but in some cases to their shape too.

Improvements

- Any potential improvements?

    Unlike other specializations like ophthalmology, urology-related surgeries are performed standing. It would be great to have some kind of seat that allows you to maintain the hips and back supported while in an almost stood position.

Demographic data

Identification (A, B, C, etc.)	F
Age	27
Gender	Female
Weight (kg)	68
Height (cm)	167
Sitting acromial (cm)	57
Acromion height (cm)	138
Shift duration	8-24 hours
Active years	2
Speciality	Neurosurgery
Surgery room (specific operations)	—
Centre	San Juan de Dios Hospital, Tenerife, Spain

Questions

Subjective vision

- Do you think you have had pain due to your work as a surgeon? Where?
  - Yes, in head and in the lower back.
- Which parts do you suffer the most during long operations? How many per week?
  - Lower back and neck. Maybe two long operations per week.
- Which parts do you suffer the most during short operations? How many per week?

  - During short operations I have not feel any pain. I have, maybe, 4 short operations per week.

Intensity, duration & frequency

- How many times do you operate a day? How many times per week?
  - 1 or 2 times per day, 3 times per week. So each week, between 3 and 6 times.
- What is the operations' time span?
  - Between 3 and 18 hours.
- Which are the most demanding operations? How often do you perform those operations?
  - Those in which we need to keep standing for a long time and those in which we need to use the microscope. And we have those operations 2 times per week.

Individual experience

- Which are the rarest or uncomfortable postures for the hands (or upper limbs)?
  - Making a drill bit: with the right hand, grasp the motor perpendicular to the skull and slightly force it in the same position. With the contralateral hand you have to force in the opposite direction so that it does not sink.
  - Also using the laminotome: instrument similar to tweezers to cut. That it is necessary to make force with one hand and with the other force in the opposite direction so that it does not sink.
- Could you describe two postures (in context) that are especially uncomfortable?
  - We always operate in the same posture: standing.

- Could you enumerate the following parts according to the overall soreness experienced? Neck, shoulders, lower back, upper limbs, hands, and legs.

  Neck, lower back, shoulders, upper limbs, hands and legs.

- Have you received training related to patient handling (referred to ergonomics) before? Do you apply the principles learned?

  No, never. I have not received that kind of training.

Previously identified problems
- Do you think that there are some external factors that compromise the quality of the ergonomics? Which ones? (surgical instruments, bed's height)

  Surgical instruments are OK. But it would be great if we were not standing during the full operation.

Improvements
- Any potential improvements?

  I have never thought about it.

10.1.4 Questionnaires with surgeons

	Posture	Never	Seldom	Sometimes	Often	Very often
Trunk Posture						
	Straight upright				x	
	Bent half-way forward (about 45º)			x		
	Bent very forward (about 75º)		x			
	Twisted/rotated		x			
	Bent to the side		x			
Arm position						
	Both arms raised so that elbows are above chin height		x			
	One arm raised so that elbow is above chin height		x			
	Both arms raised so that elbows are above chest height			x		
	One arm raised so that elbow is above chest height				x	
	Both elbows below chest height					x
Leg Position						
	Sitting				x	
	Standing					x
	Squatting	x				
	Kneeling (on one or both knees)	x				
	Walking, moving					x
Lifting pushing, pulling or carry with upright trunk posture						
	Light force (up to 11kg)		x			
	Moderate force (11-23 kg)	x				
	Heavy/high force (more than 23 kg)	x				
Lifting, pushing, pulling or carry with bent trunk						
	Light weight or force (up to 11 kg)		X			
	Moderate weight or force (11-23 kg)	x				
	Heavy weight or force (more than 23 kg)	x				

Posture		Never	Seldom	Sometimes	Often	Very often
Trunk Posture						
	Straight upright					x
	Bent half-way forward (about 45º)				x	
	Bent very forward (about 75º)		x			
	Twisted/rotated		x			
	Bent to the side	x				
Arm position						
	Both arms raised so that elbows are above chin height	x				
	One arm raised so that elbow is above chin height	x				
	Both arms raised so that elbows are above chest height			x		
	One arm raised so that elbow is above chest height			x		
	Both elbows below chest height					x
Leg Position						
	Sitting					x
	Standing			x		
	Squatting	x				
	Kneeling (on one or both knees)	x				
	Walking, moving			x		
Lifting pushing, pulling or carry with upright trunk posture						
	Light force (up to 11kg)		x			
	Moderate force (11-23 kg)	x				
	Heavy/high force (more than 23 kg)	x				
Lifting, pushing, pulling or carry with bent trunk						
	Light weight or force (up to 11 kg)	x				
	Moderate weight or force (11-23 kg)	x				
	Heavy weight or force (more than 23 kg)	x				

	Posture	Never	Seldom	Sometimes	Often	Very often
	Trunk Posture					
	Straight upright					x
	Bent half-way forward (about 45º)			x		
	Bent very forward (about 75º)			x		
	Twisted/rotated		x			
	Bent to the side	x				
	Arm position					
	Both arms raised so that elbows are above chin height	x				
	One arm raised so that elbow is above chin height	x				
	Both arms raised so that elbows are above chest height			x		
	One arm raised so that elbow is above chest height		x			
	Both elbows below chest height					x
	Leg Position					
	Sitting			x		
	Standing					x
	Squatting	x				
	Kneeling (on one or both knees)	x				
	Walking, moving	x				
	Lifting pushing, pulling or carry with upright trunk posture					
	Light force (up to 11kg)			x		
	Moderate force (11-23 kg)	x				
	Heavy/high force (more than 23 kg)	x				
	Lifting, pushing, pulling or carry with bent trunk					
	Light weight or force (up to 11 kg)	x				
	Moderate weight or force (11-23 kg)	x				
	Heavy weight or force (more than 23 kg)	x				

Lisa, nurse

About

· Age: 24
· Status: Single
· Location: Las Palmas de Gran Canaria, Spain

· Post: Nurse
· Workplace: General Hospital José Molina
· Experience: 3 year

Frustrations

· Although conscious that is not her fault, she is easily moved when some patients fail to overcome the illness.
· She always thinks that something could have been done better, and it leads her to feel insecure.

Motivations

· Helping people recover from their illnesses to return to their normal lifes.
· Feels that is our duty to take care of those who are not going through a good time.

" *Taking care of each other is everyone's job. For nurses, is our duty.*"

Bio

Lisa is in her first year of nursing apprenticeship in a hospital. For several years, she has been playing volleyball, her passion. Since she started working, though, it has been difficult to combine both things. She quitted volley and started going to the gym sometimes. As a novice, she performs many different tasks such as measuring blood pressure or changing serum providers. Occasionally, she also participates in surgeries as a theatre nurse where she has to stand still for several hours. Due to work overload, she has no time to perform tasks with the caution needed. In this sense, transferring patients or changing medication without adjusting bed height and other equipment dimensions can mean a pain in the lower back.

Fig. 34. Persona 1: Lisa, a nurse.

Daniel, nurse

About

- Age: 25
- Status: Separated
- Location: Lanzarote, Canary Islands, Spain

- Post: Nurse
- Workplace: Primary health centre Puerto Carmen
- Experience: 3 years

Frustrations

- Daniel does not mind to spend as much time as necessary working hard. However, sometimes patients do not receive the best attention, just because equipment is not good enough. He claims for the best work conditions, and he feels devastated when injuries in the workplace or patients' health risks could have been avoided.

Motivations

- Proponent of work well done
- Great respect for the sciences and medicine
- Spirit of sacrifice
- His aim is to fight against the illness; to help the patient is the consequence.

" There is only one way to do things: the right way."

Bio

Daniel has been working for four years in a primary health centre. He combines the shifts at this centre with visits to their patients' homes. According to Daniel, at primary health centres, quality of the equipment is lower compared to hospitals. "Equipment is completely behind the times: beds height is not adjustable, tools and instruments are in very bad conditions, and quite often electronic devices need to be repaired". On the other hand, he describes home visits as the most demanding part of the work, since those patients have normally reduced mobility and there is not mobile equipment that he can bring to the residences. In consequence, he has to adapt to specific conditions each time, which leads him to adopt weird and dangerous postures when it comes to change medication and healing procedures.

Fig. 35. Persona 2: Daniel: a nurse.

Michael, surgeon

About

· Age: 27
· Status: Single
· Location: Málaga, Andalucía, Spain

· Post: Surgeon, Urology
· Workplace: University Hospital Victoria
· Experience: 2 years

Frustrations

· Michael thinks that comfort in his work is directly related to the quality of the service the patient will receive. For that reason, he gets annoyed when, in the middle of an operation, he realizes that is thinking about his discomfort instead of focusing on the patient.

Motivations

· Michael's love for medicine runs in the family. He enjoys with the work he has, and all what he wants is to improve working conditions so that his personal work is also the best possible.

" *The only way to improve is being aware of fails.*"

Bio

Michael is on his second year of urology training at University Hospital, in Málaga, Spain. He was born in a family of doctors so his interest in medicine comes from an early age. When it comes to his job, he considers himself as a proactive and ambitious person, always looking for ways to get better at it and improve his work environment. He sees the latter as a crucial aspect to get the best outcome of his work. However, being much taller than his colleagues has always set difficulties in his daily routine, from working on his desk to bed height in the surgery room, since it is adapted to the main surgeon. As an apprentice, his tasks in the surgery room are mainly focused on helping out his colleagues. This involves holding static postures for long periods of time, which turns into pain and soreness in the lower back and neck area.

Fig. 36. Persona 3: Michael, a surgeon.

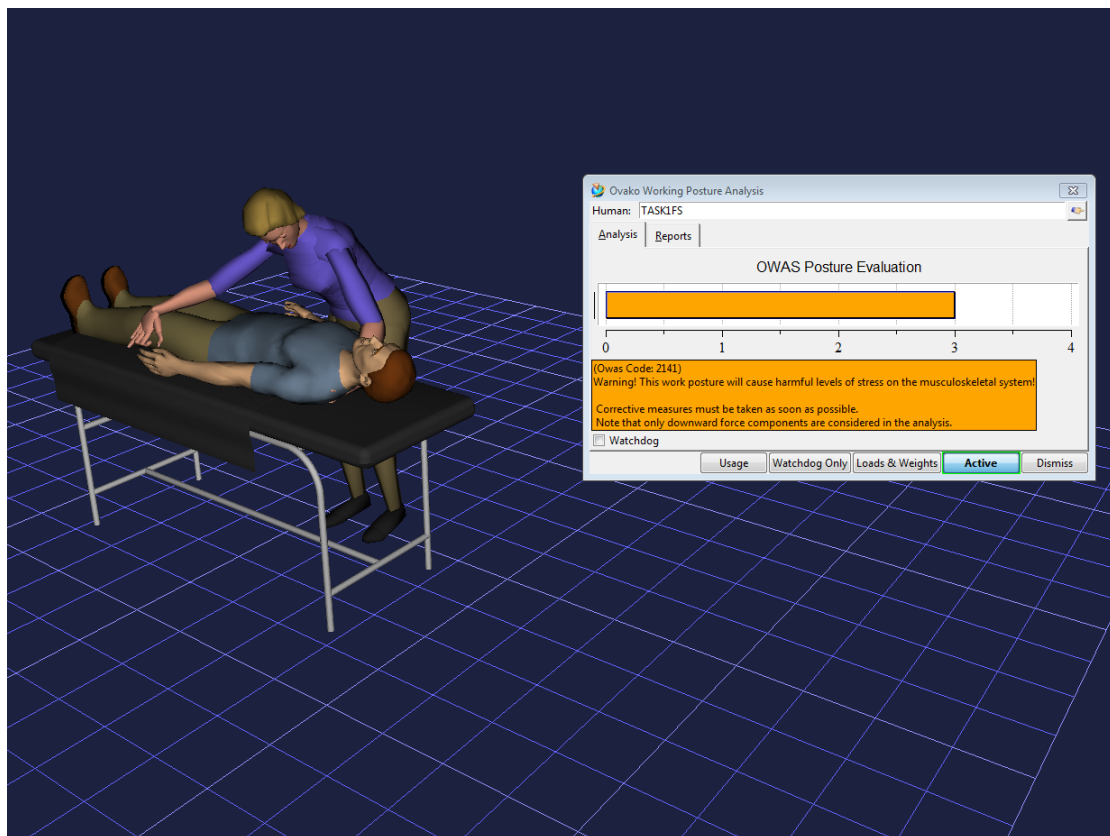## 10.3 MOTION CAPTURE RECORDING SESSION PICTURES
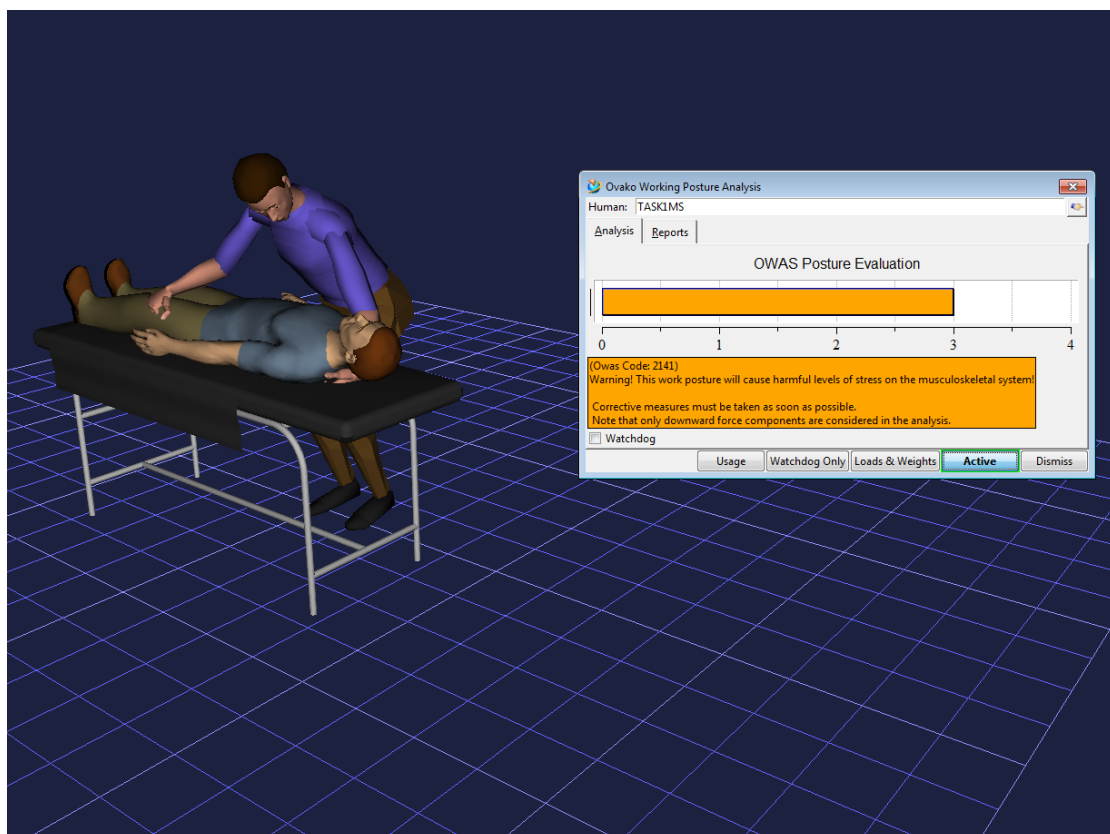

*Fig. 37. Task 1, persona 1*

Fig. 38. Task 1, persona 2

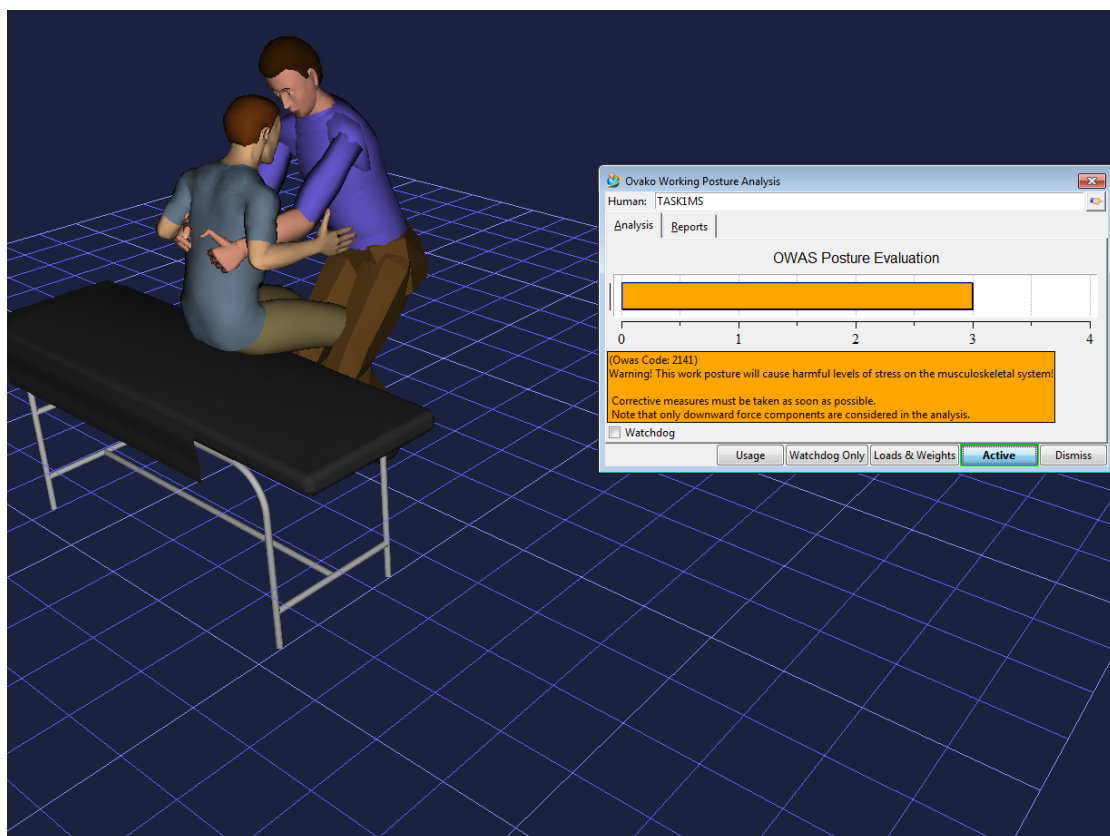*Fig. 39. Task 2, persona 1.*

*Fig. 40. Task 2, persona 2.*

*Fig. 41. Task 3, persona 1.*

*Fig. 42. Task 3, persona 2.*

*Fig. 43. Task 4, persona 1.*

Fig. 44. Task 4, persona 2.

Fig. 45. Task 5, persona 3.

Fig. 46. Task 6, persona 3.

10.4 MVN ANALYZE SIMULATION PICTURES

Fig. 47. Task 1, persona 1.
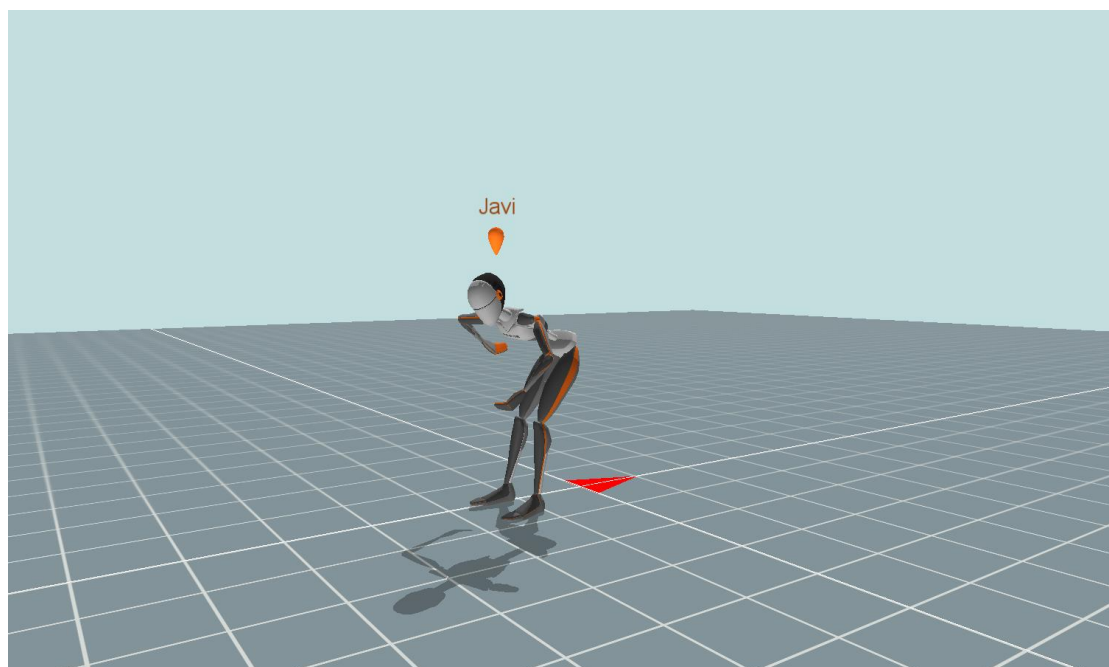
Fig. 48. Task 1, persona 2.
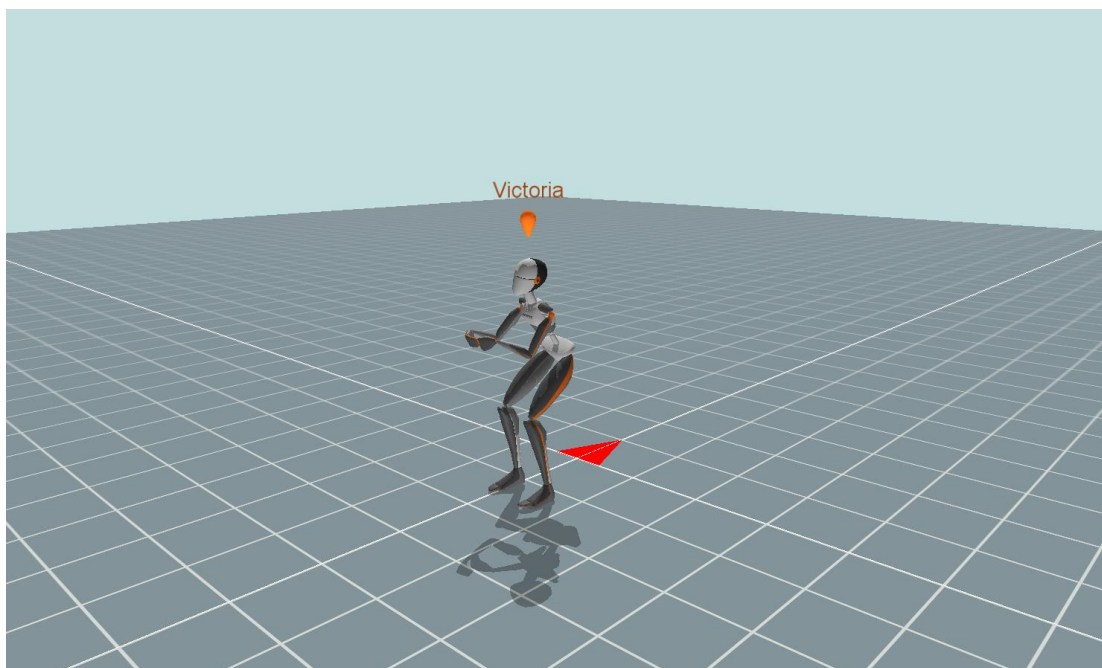
Fig. 49. Task 2, persona 1.
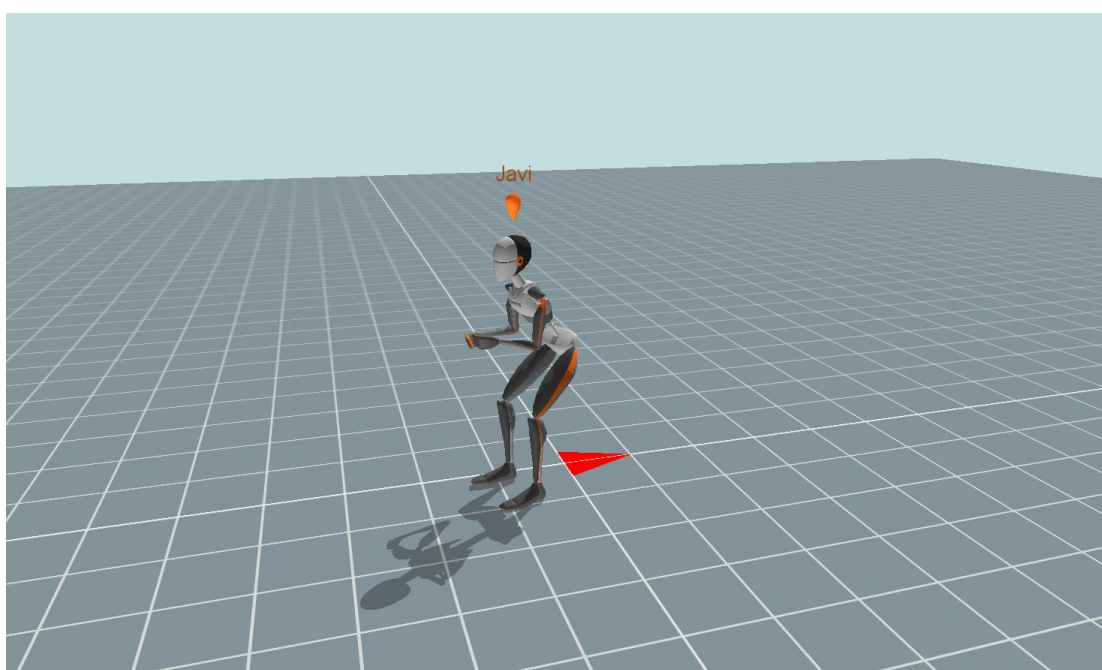
Fig. 50. Task 2, persona 2.
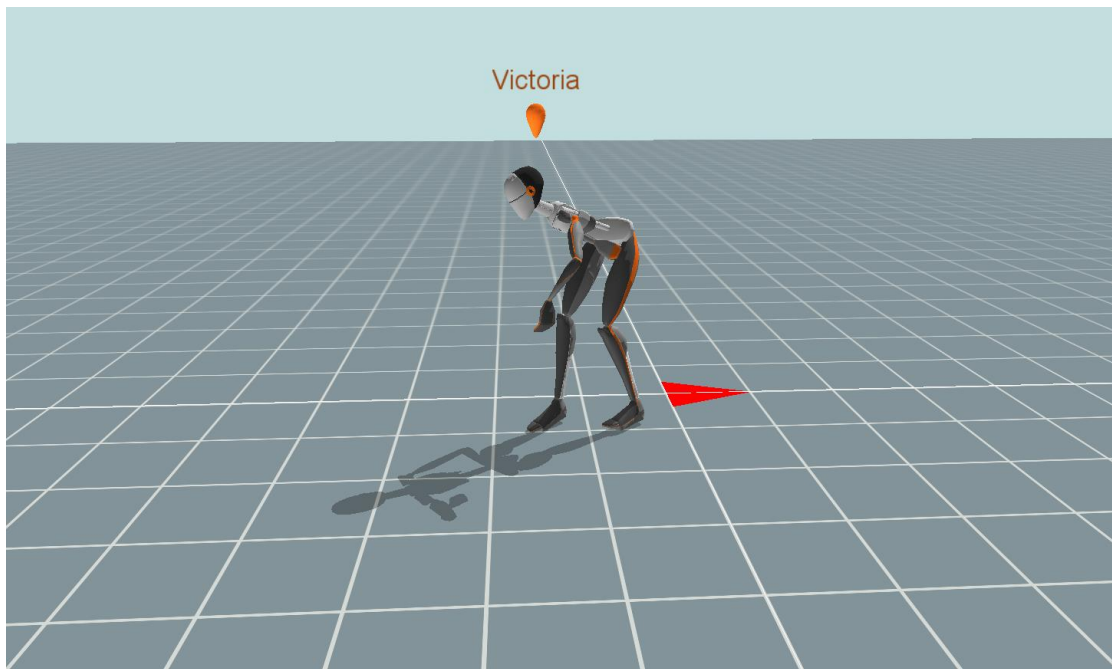
Fig. 51. Task 3, persona 1.
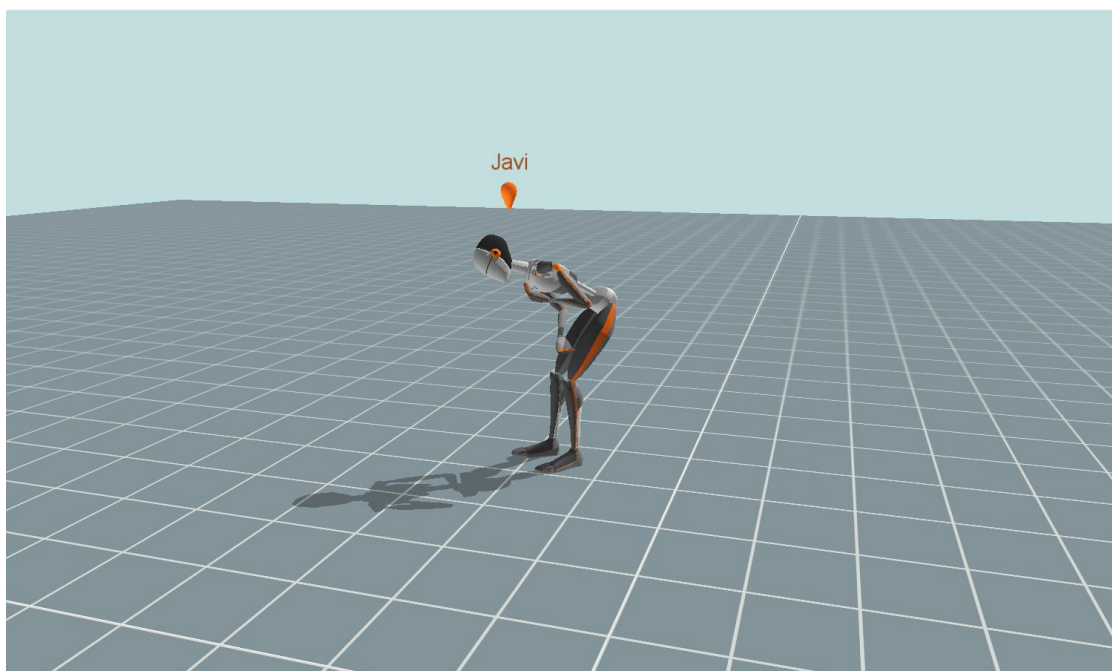
Fig. 52. Task 3, persona 2.
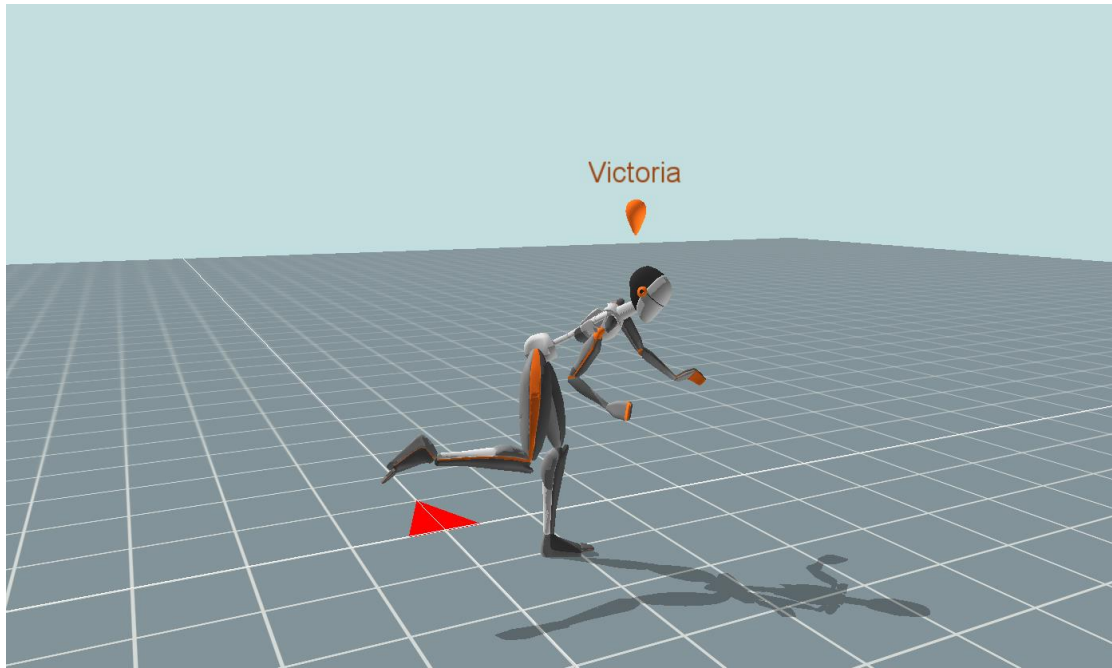
Fig. 53. Task 4, persona 1.
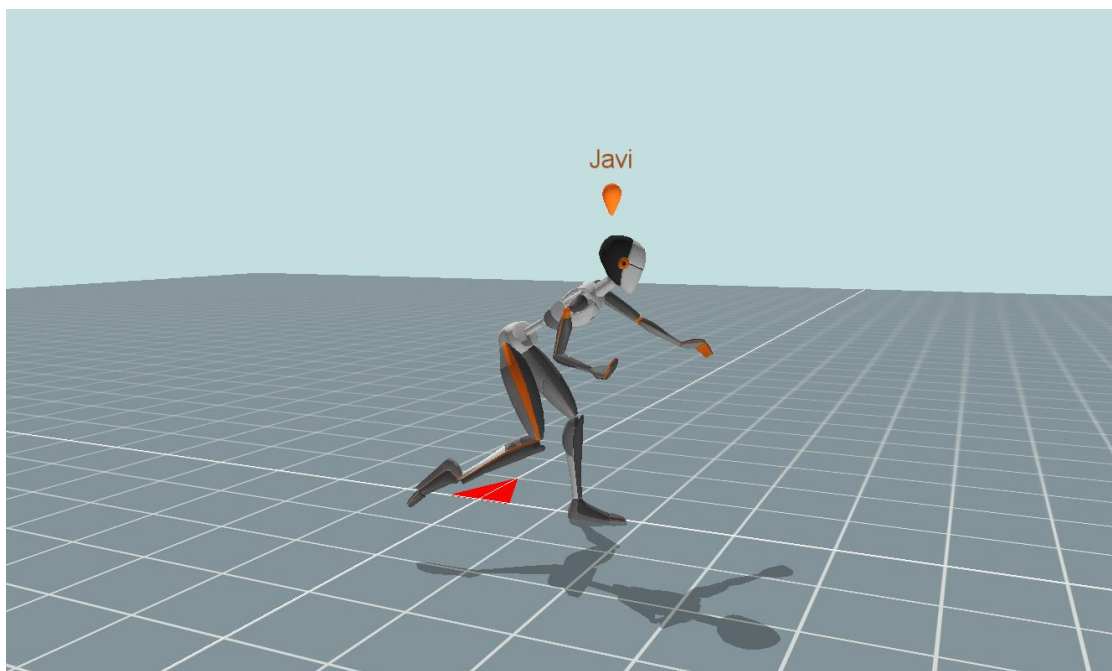
Fig. 54. Task 4, persona 2.
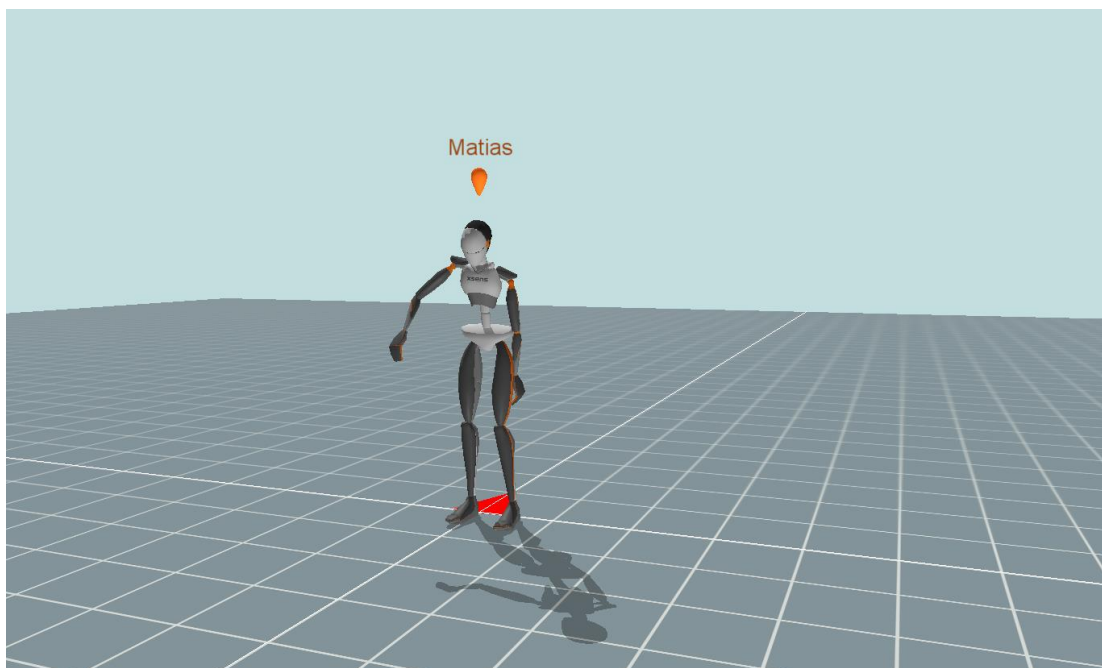
Fig. 55. Task 5, persona 3.
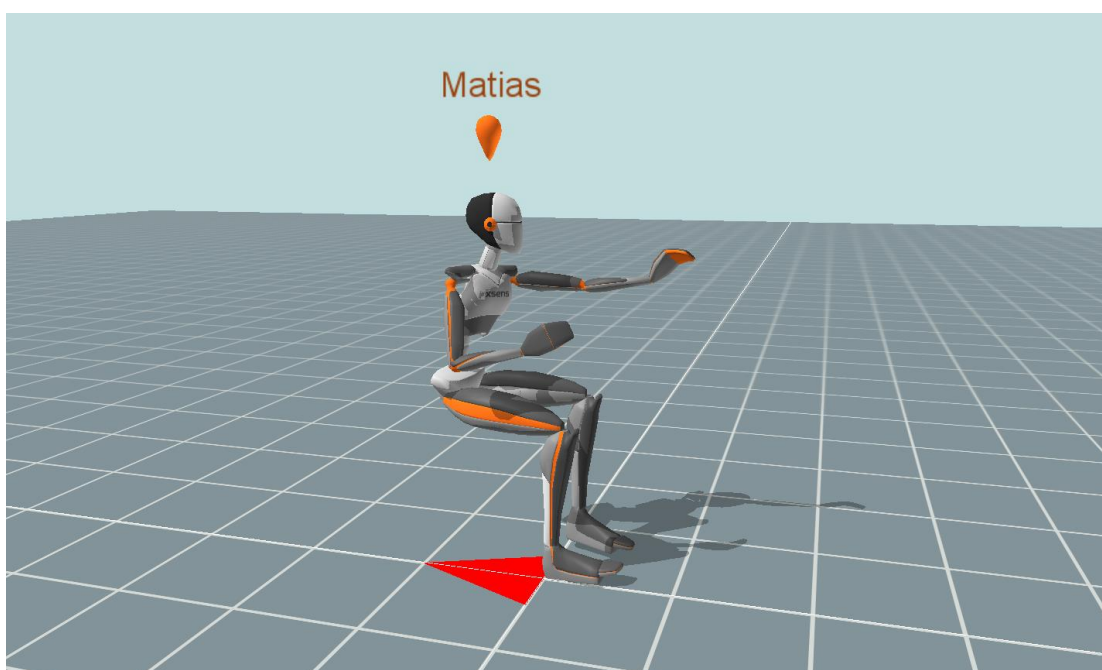
Fig. 56. Task 6, persona 3.

10.5 IPS IMMA TASKS RESULTS
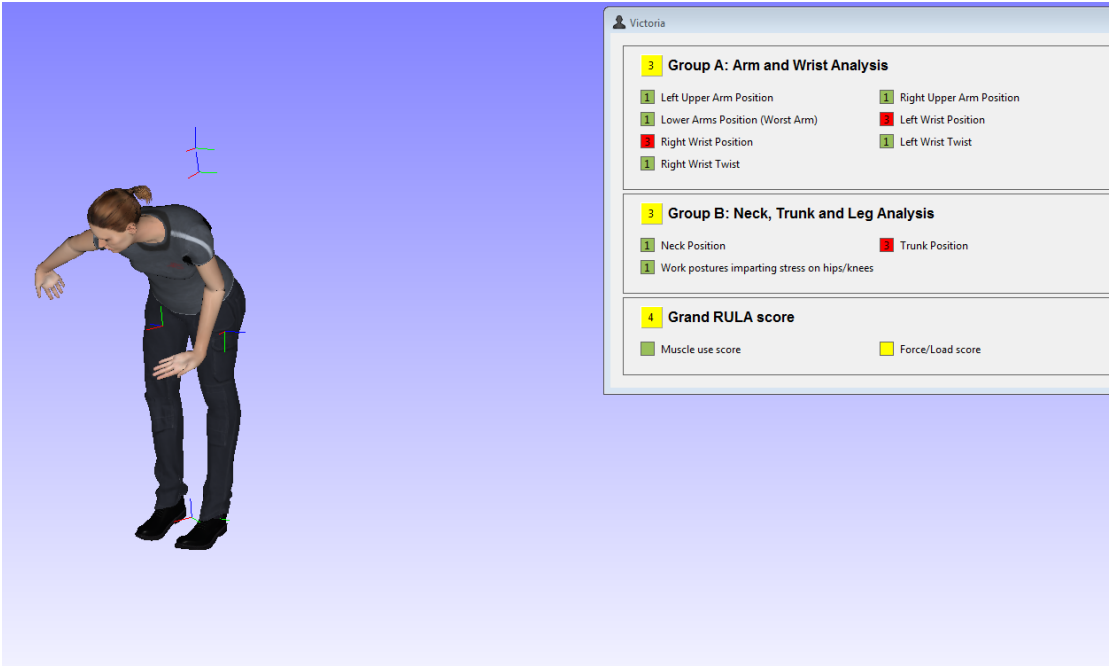
Fig. 57. Task 1, persona 1.
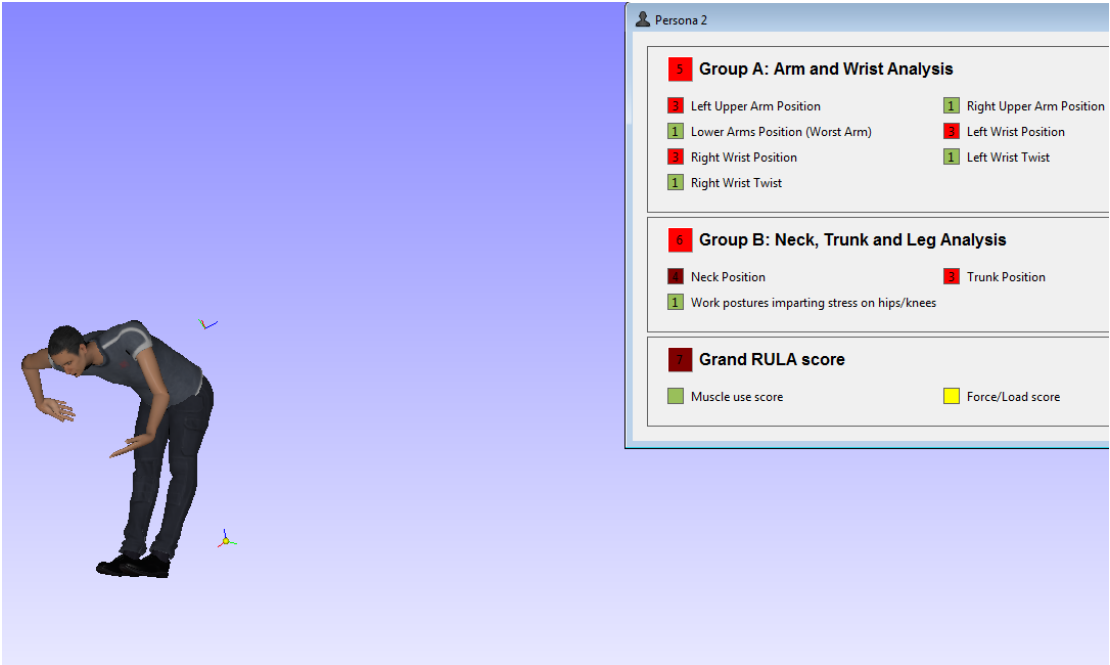
Fig. 58. Task 1, persona 2.

Fig. 59. Task 2, persona 1.
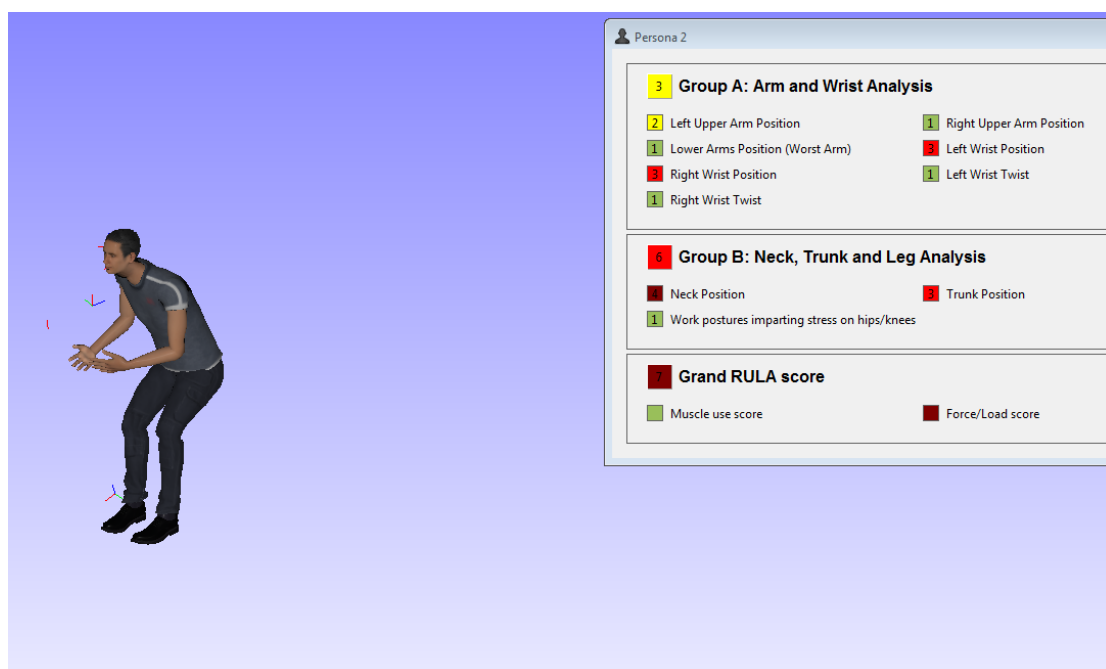
Fig. 60. Task 2, persona 2.

Fig. 61. Task 3, persona 1.
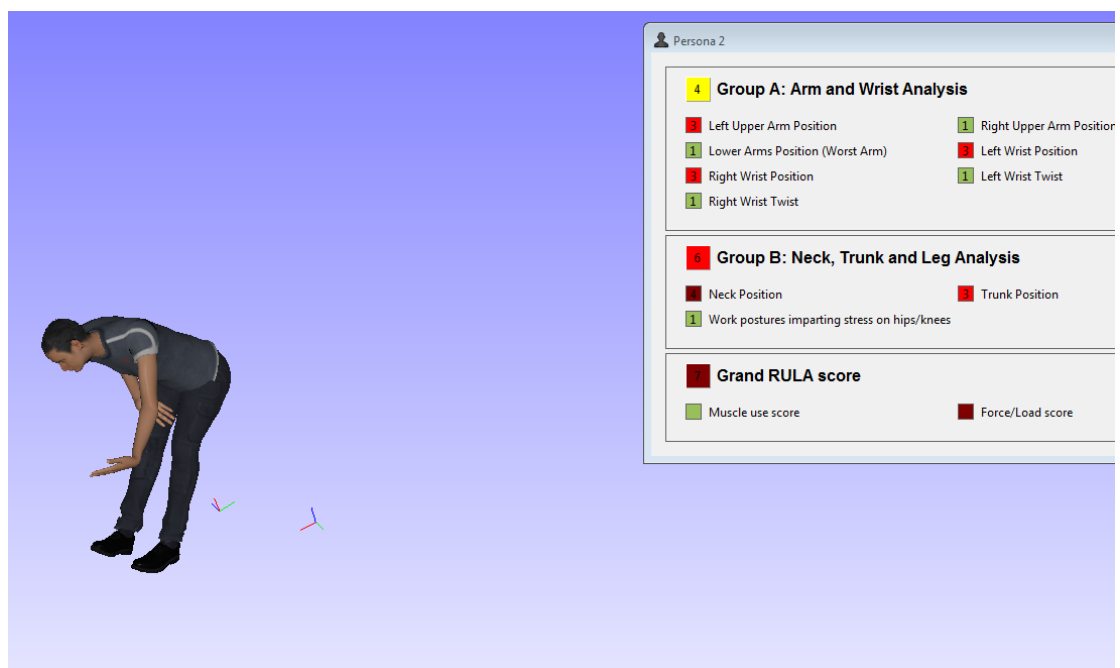
Fig. 62. Task 3, persona 2.
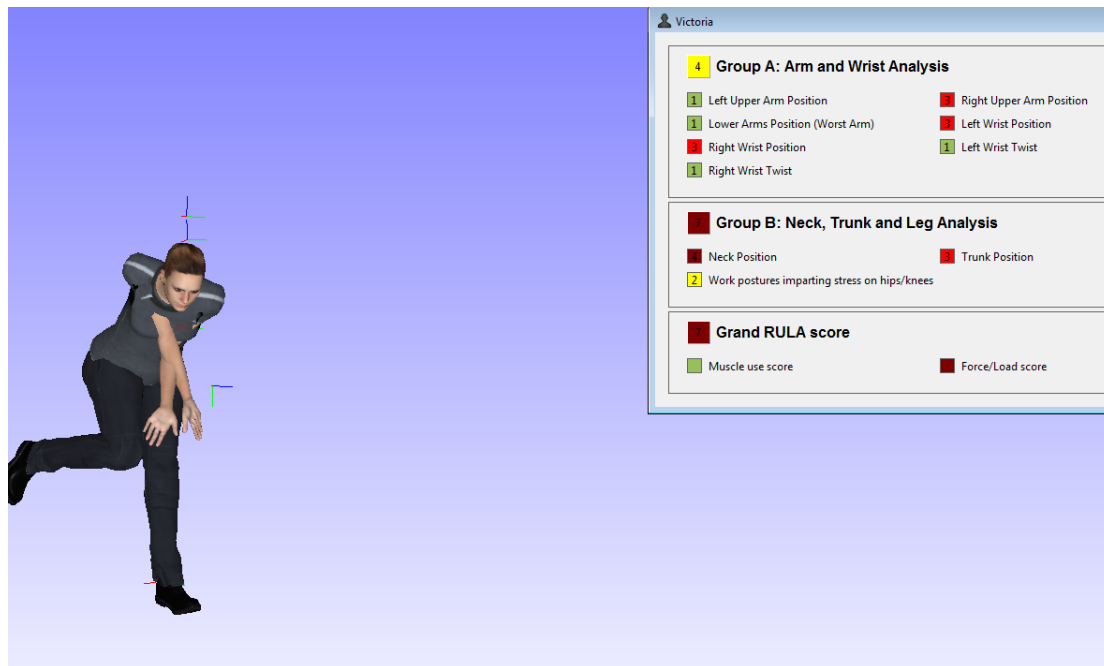
Fig. 63. Task 4, persona 1.
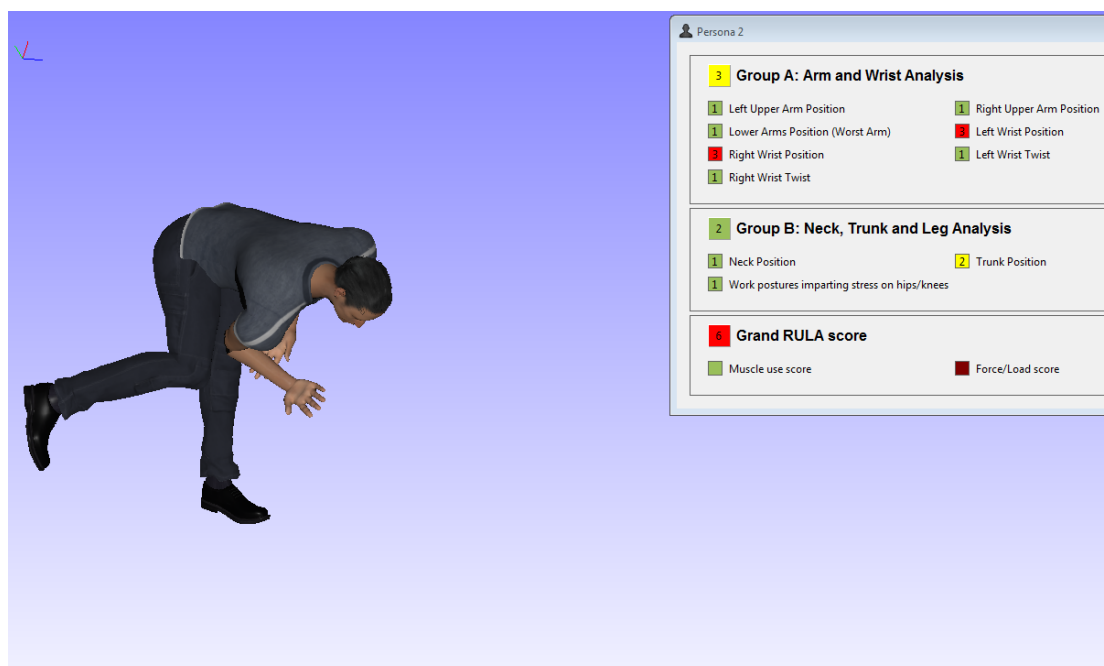
Fig. 64. Task 4, persona 2.
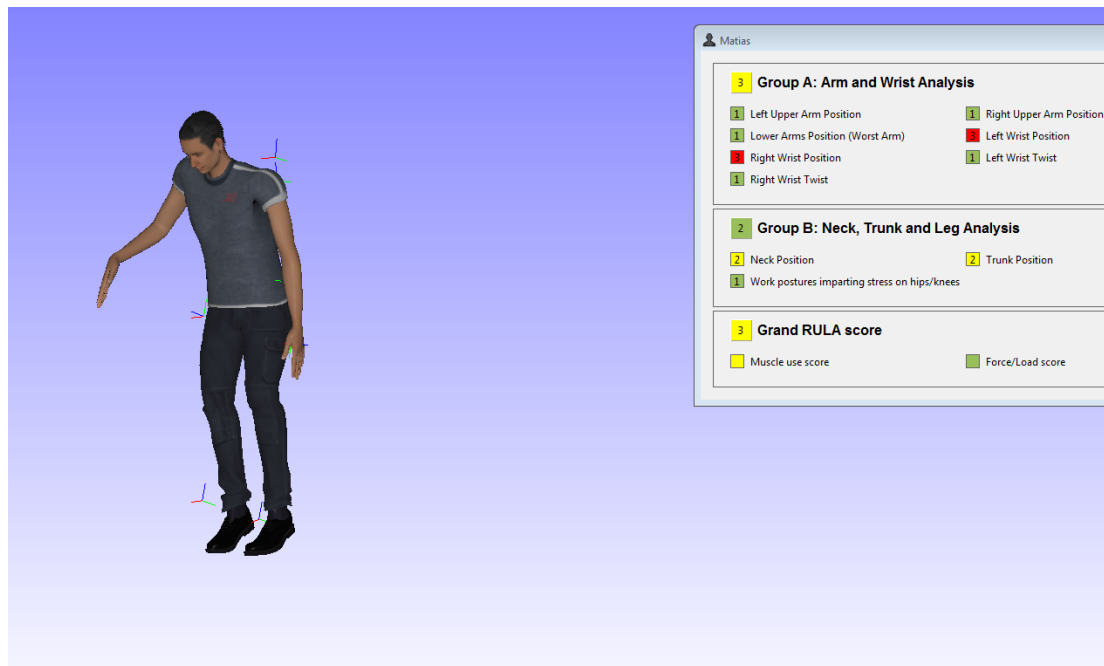
Fig. 65. Task 5, persona 3.
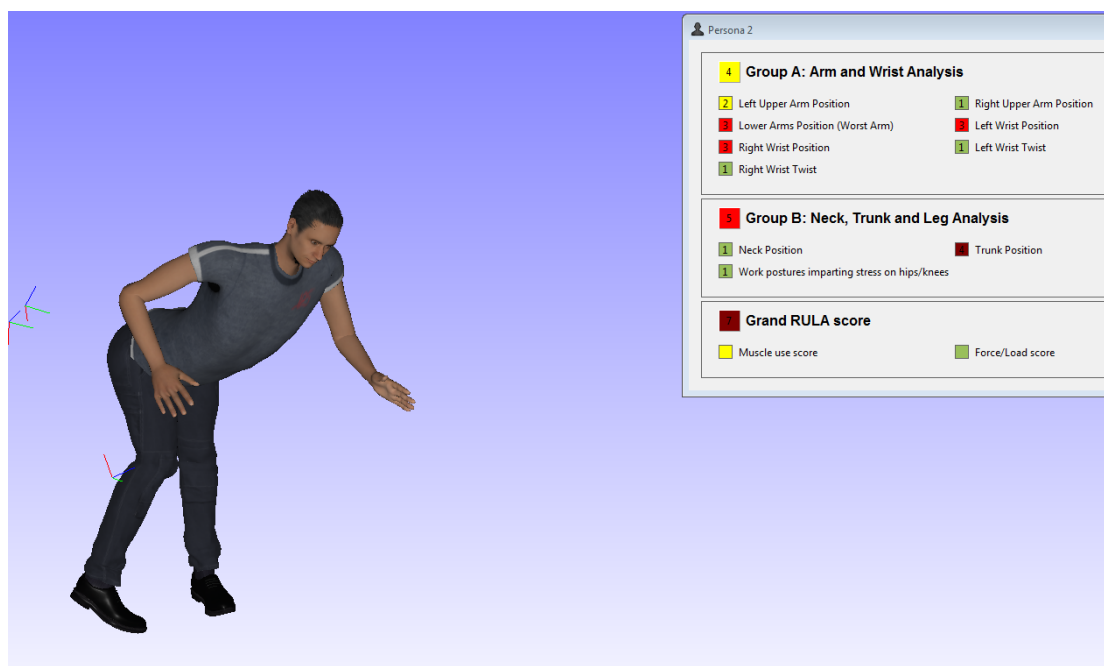
Fig. 66. Task 6, persona 3.

10.6 JACK TECNOMATIX TASKS RESULTS

10.6.1 RULA Results
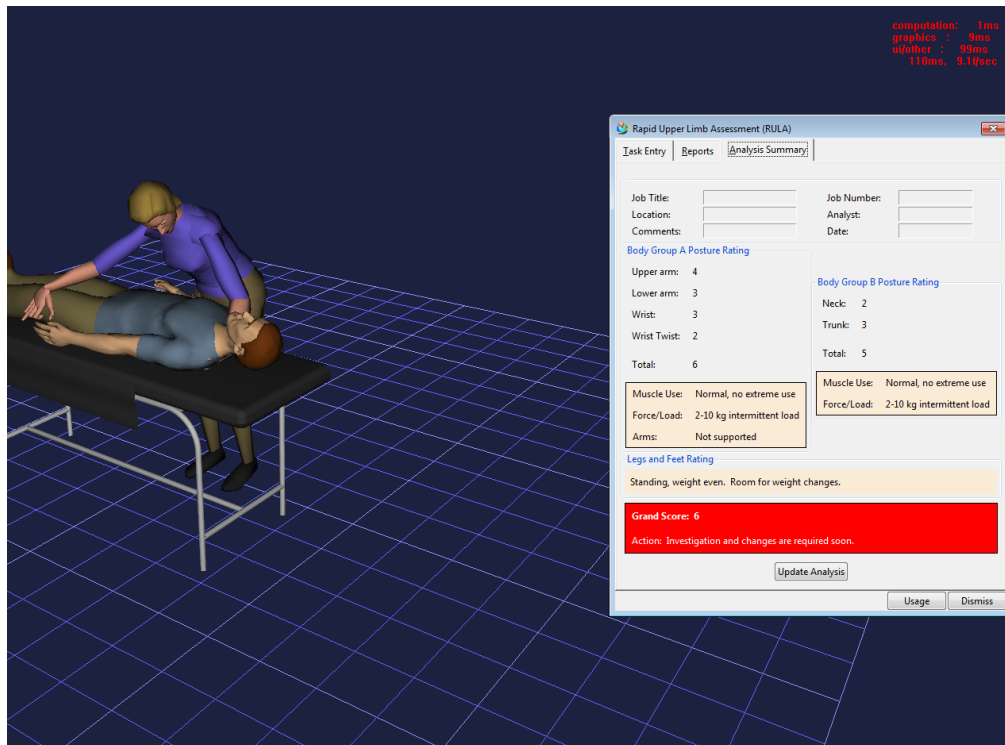
Fig. 67. Task 1, persona 1.
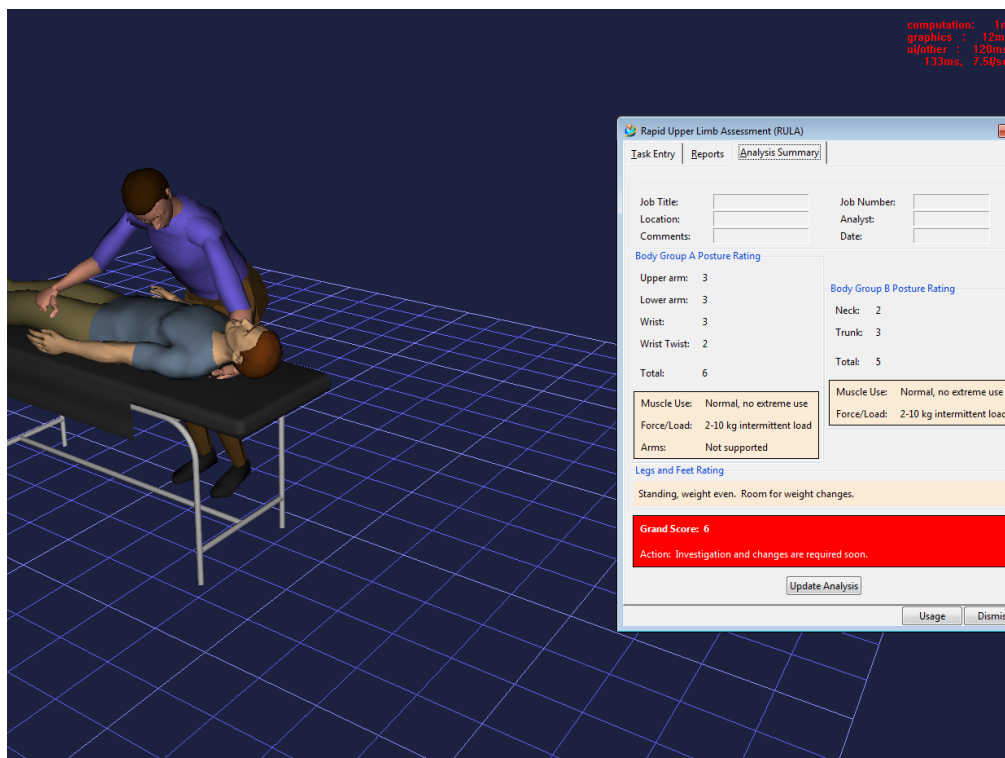
Fig. 68. Task 1, persona 2.
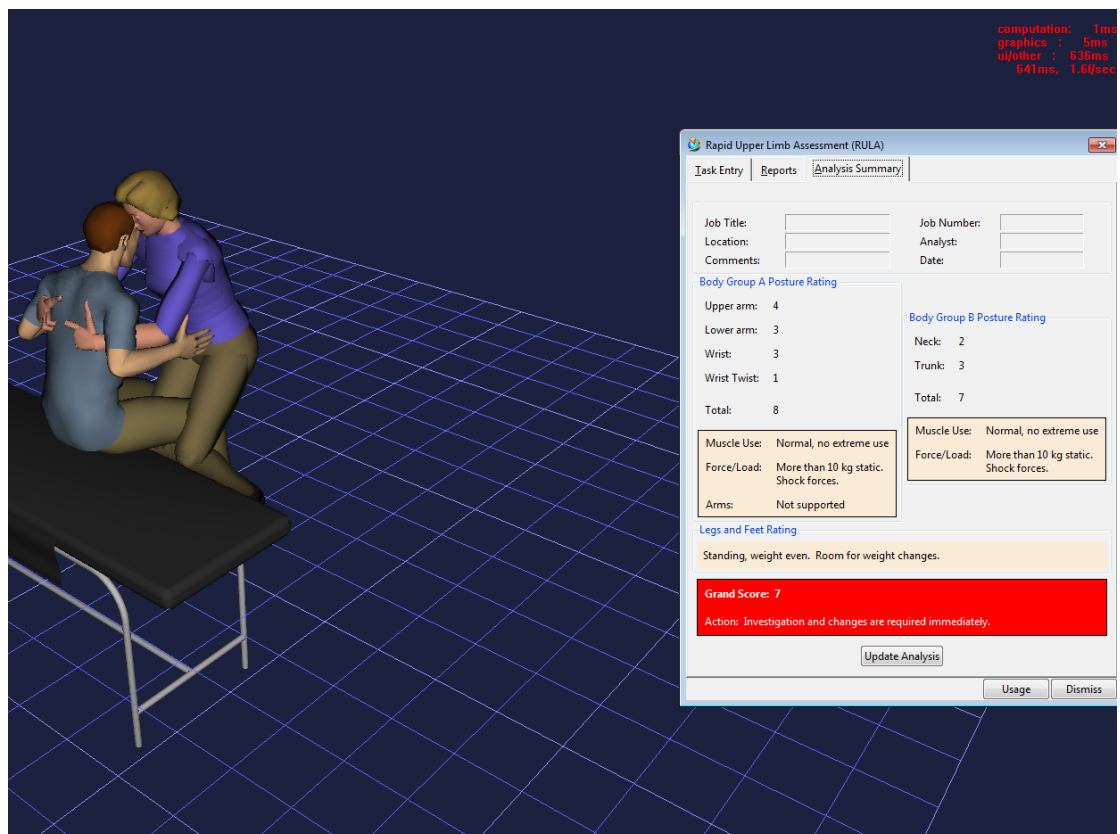
Fig. 69. Task2, persona 1.
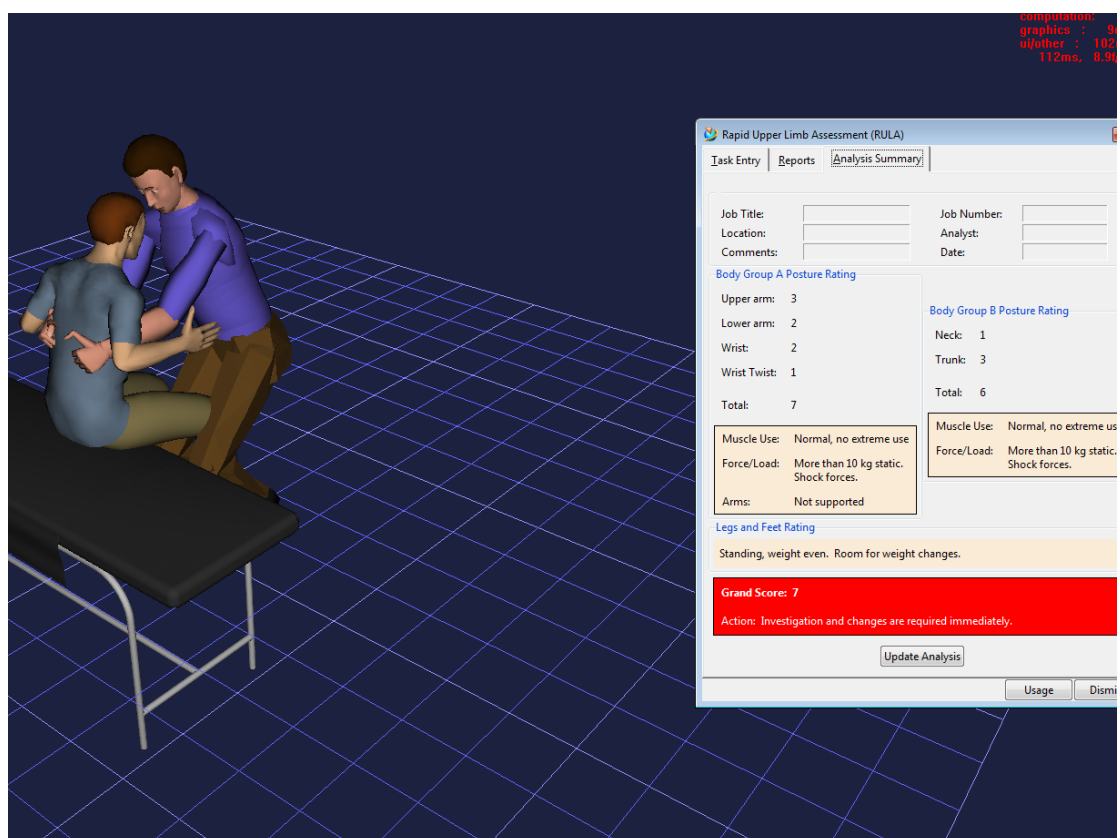
Fig. 70. Task 2, persona 2.
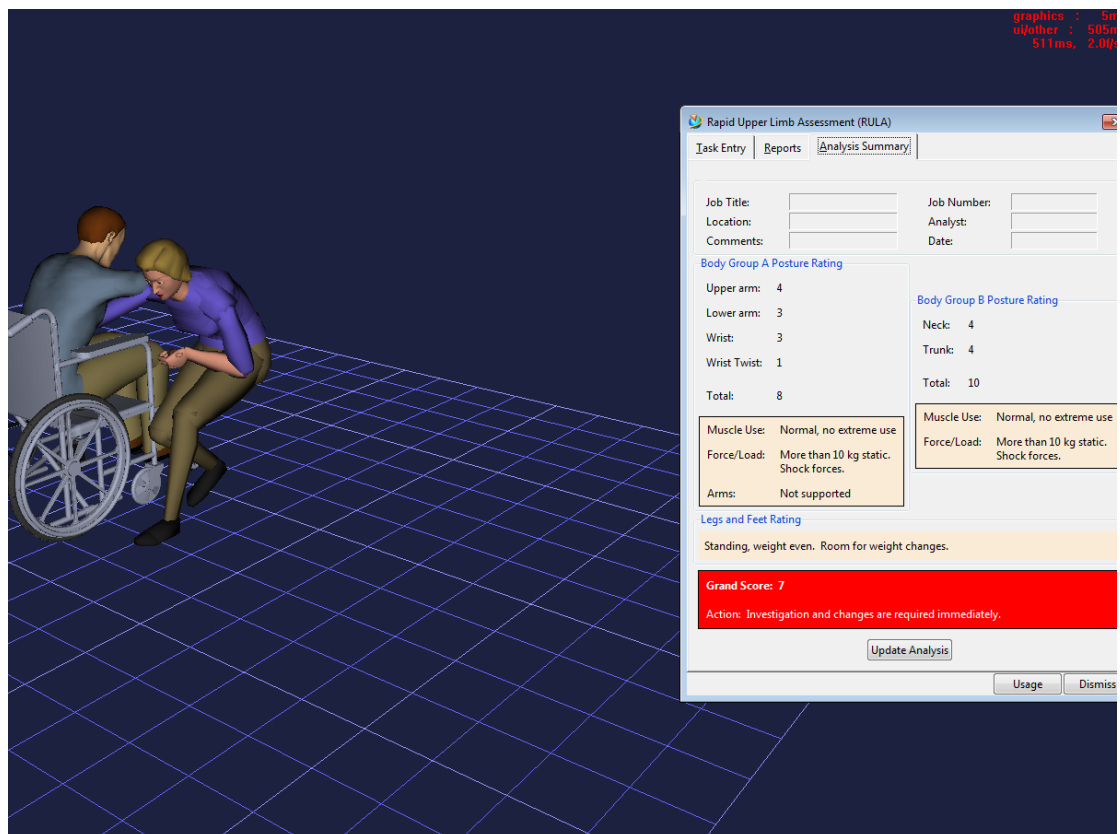
Fig. 71. Task 3, persona 1.
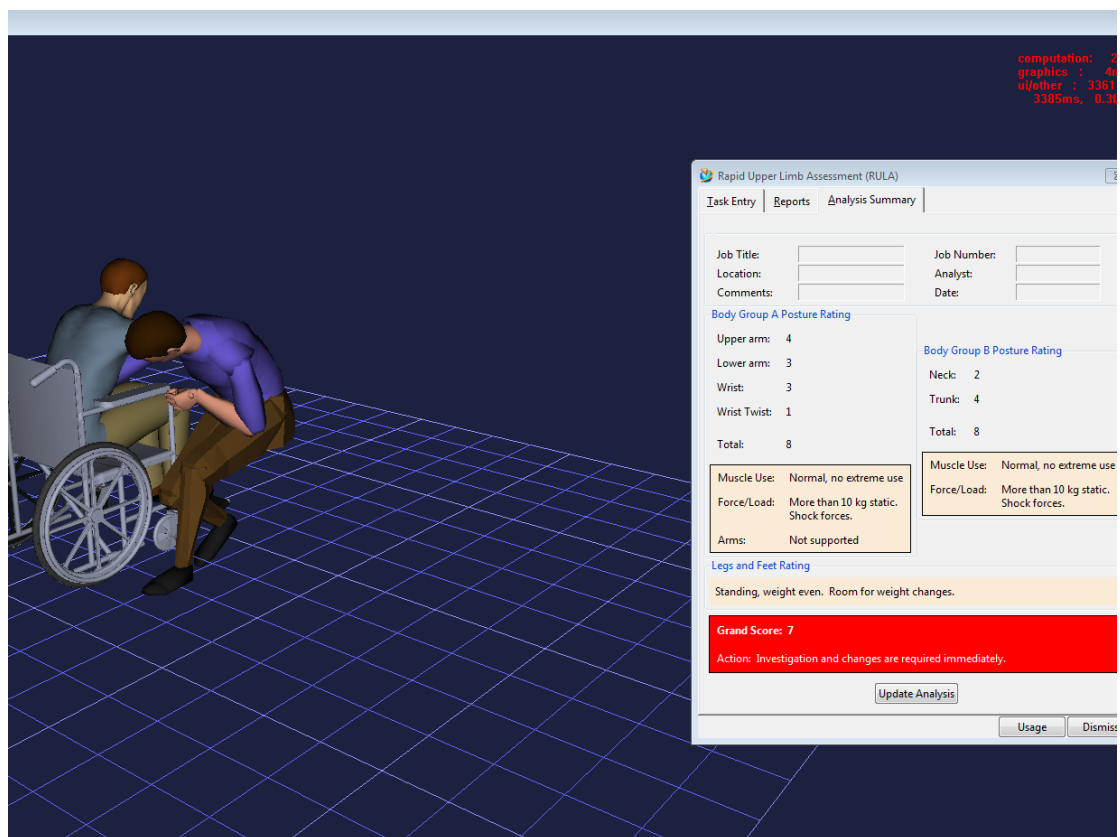
Fig. 72. Task 3, persona 2.
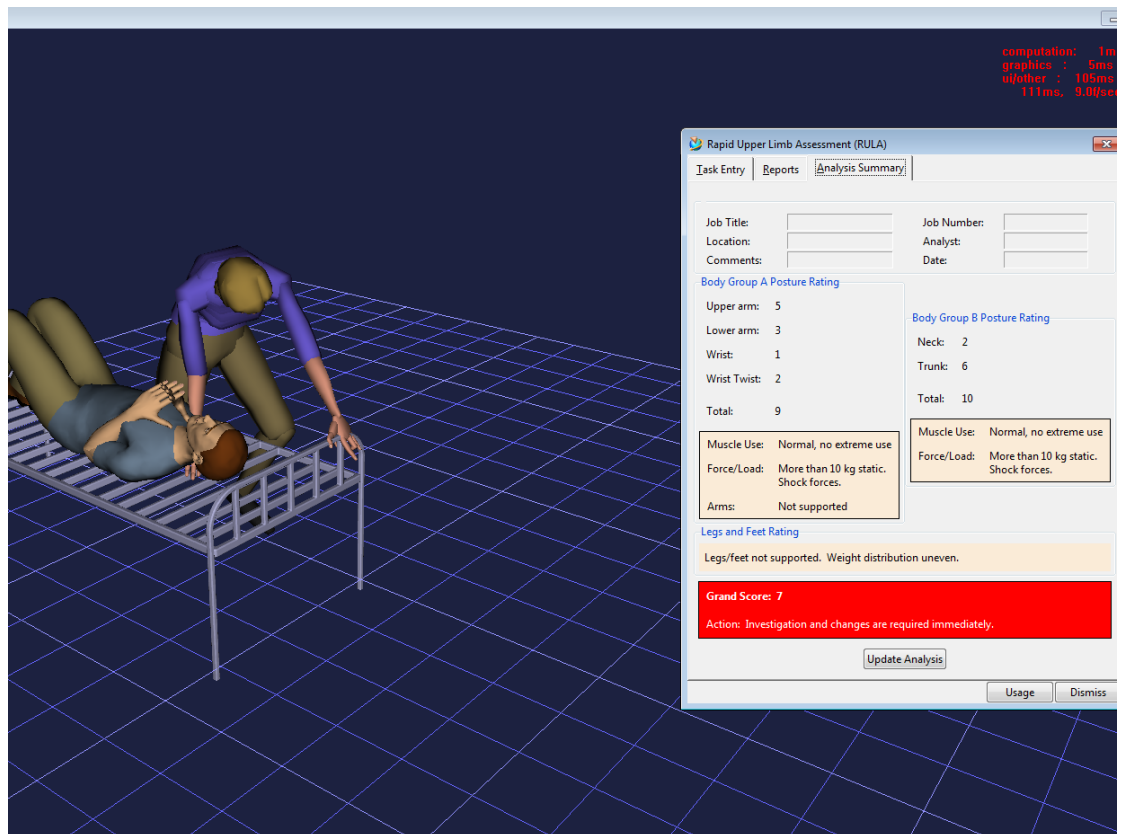
Fig. 73. Task 4, persona 1.
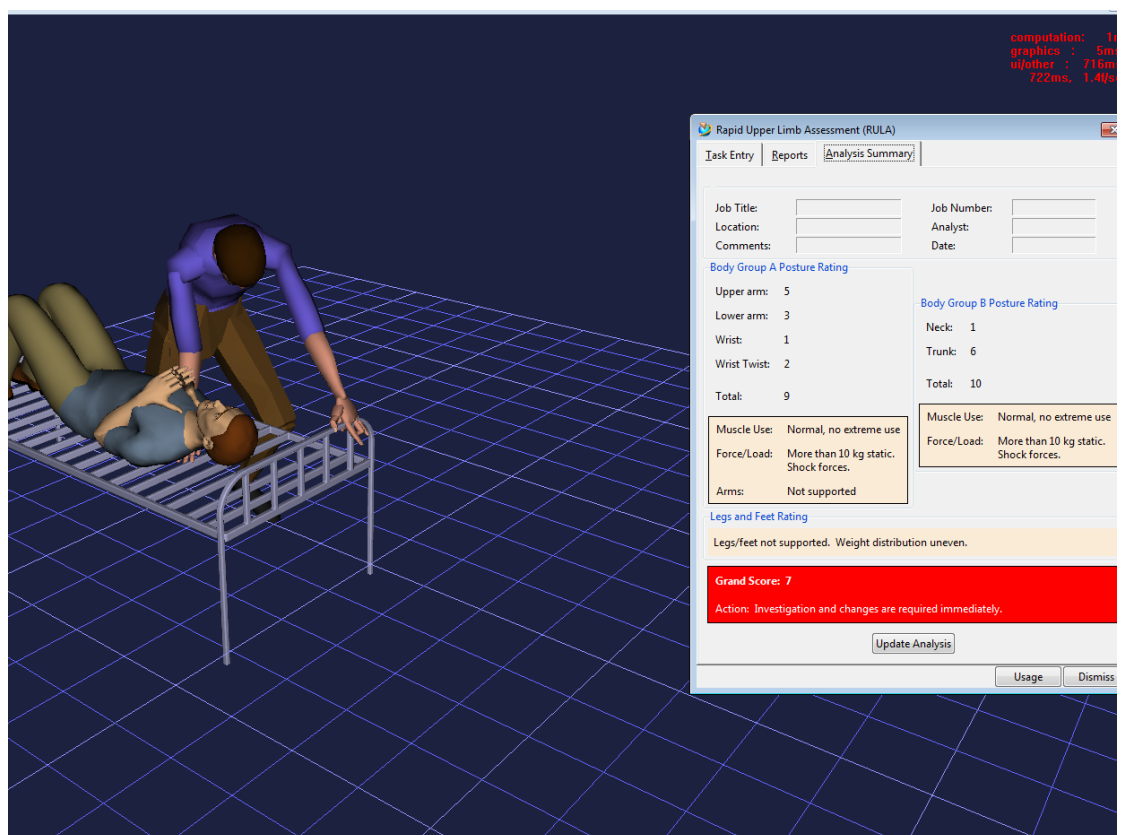
Fig. 74. Task 4, persona 2.
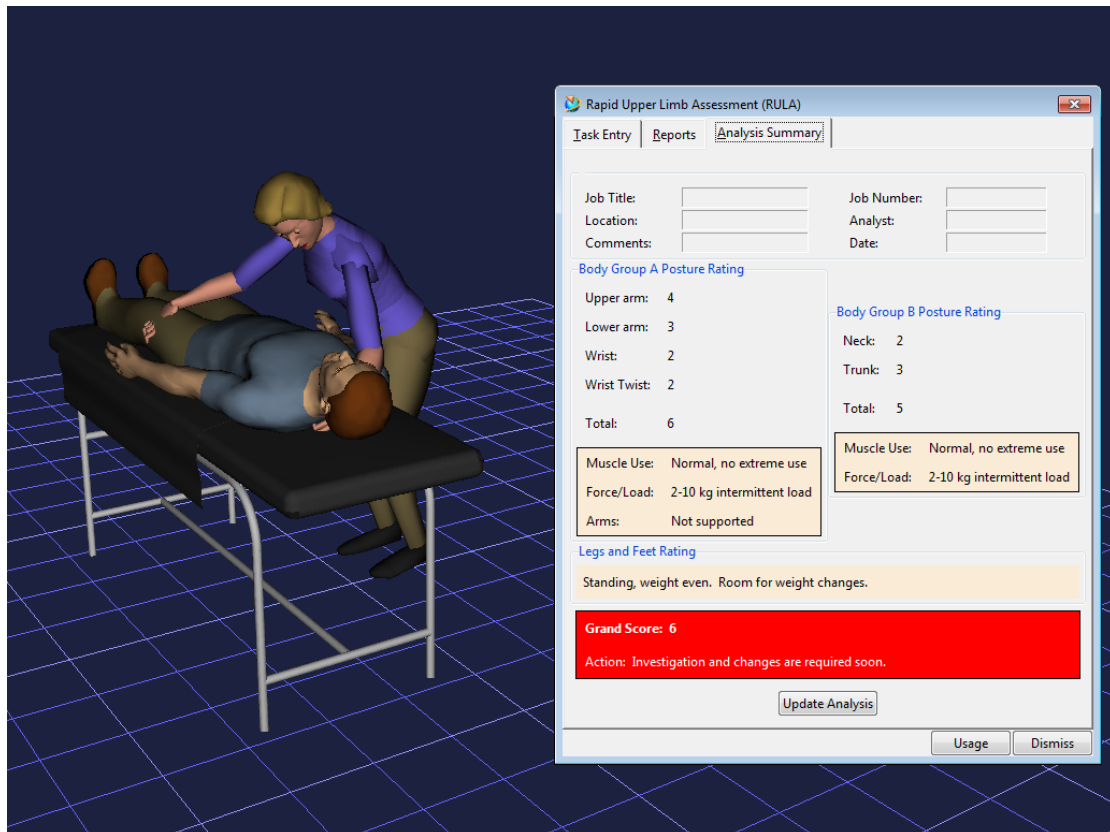
Fig. 75. Task 1, female 1.
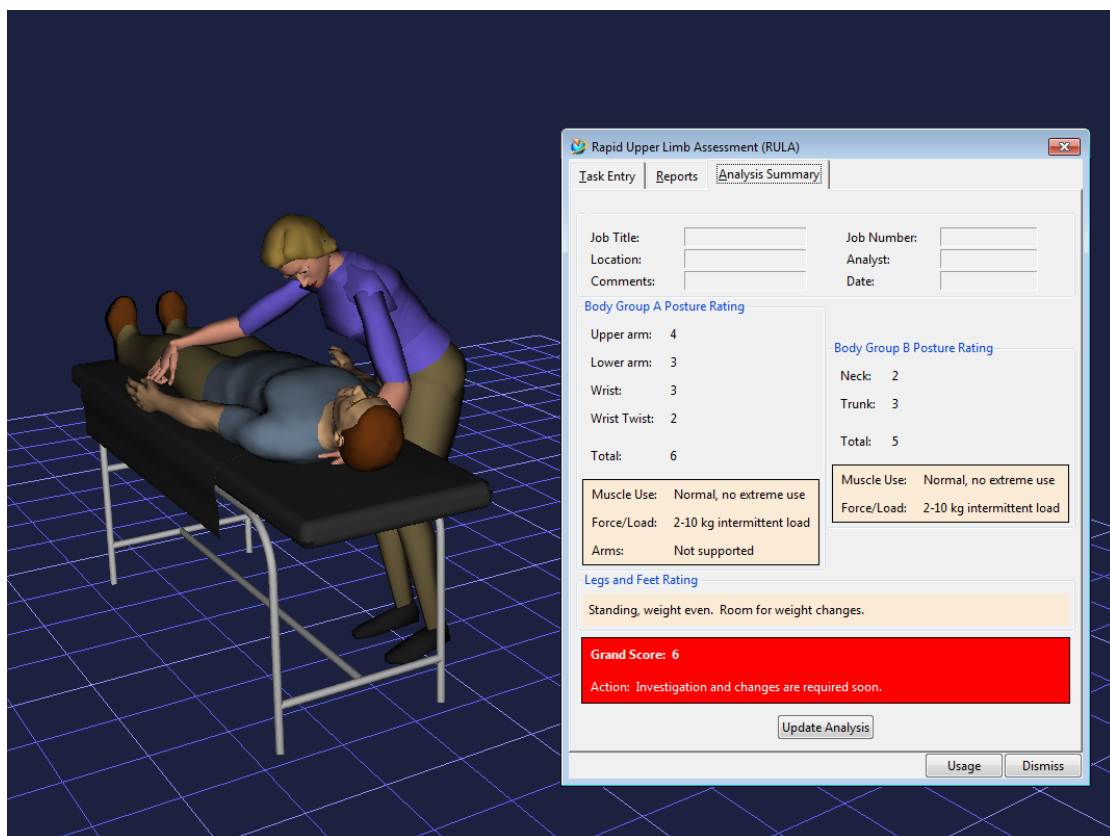
Fig. 76.Task 1, female 2.
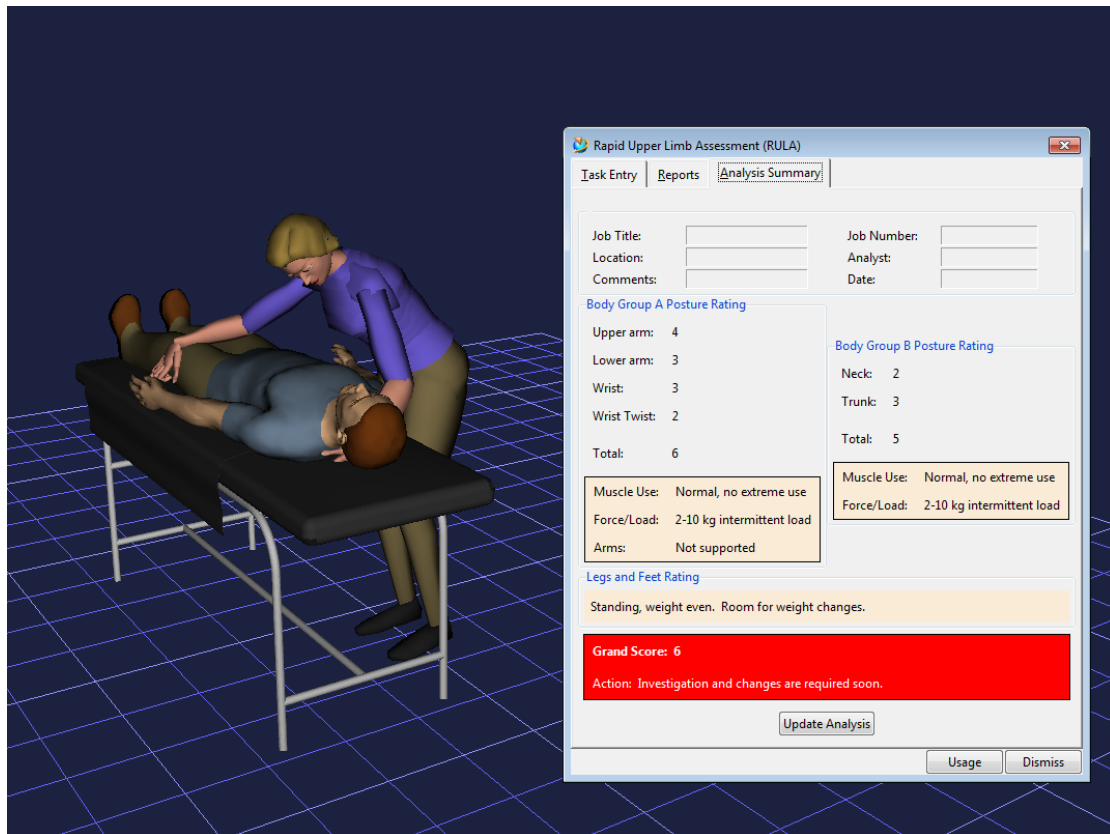
Fig. 77. Task 1, female 3.
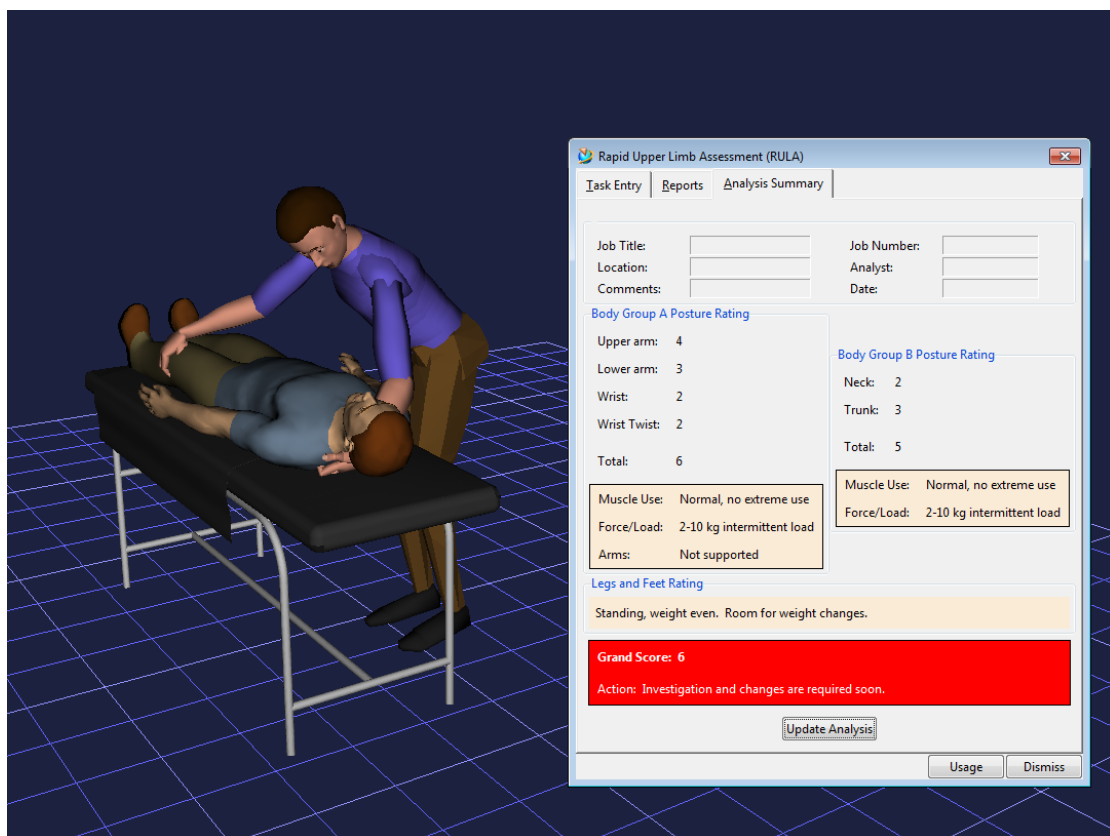

Fig. 78. Task 1, male 4.
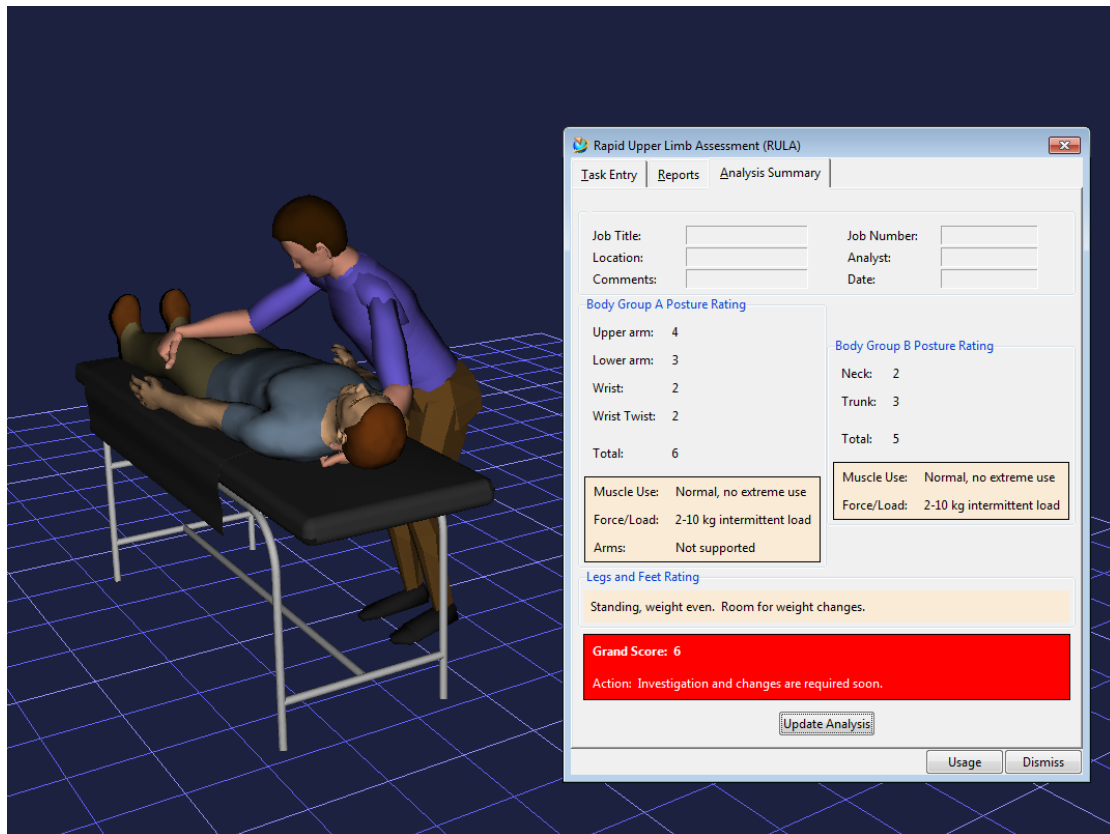
Fig. 79. Task 1, male 5.
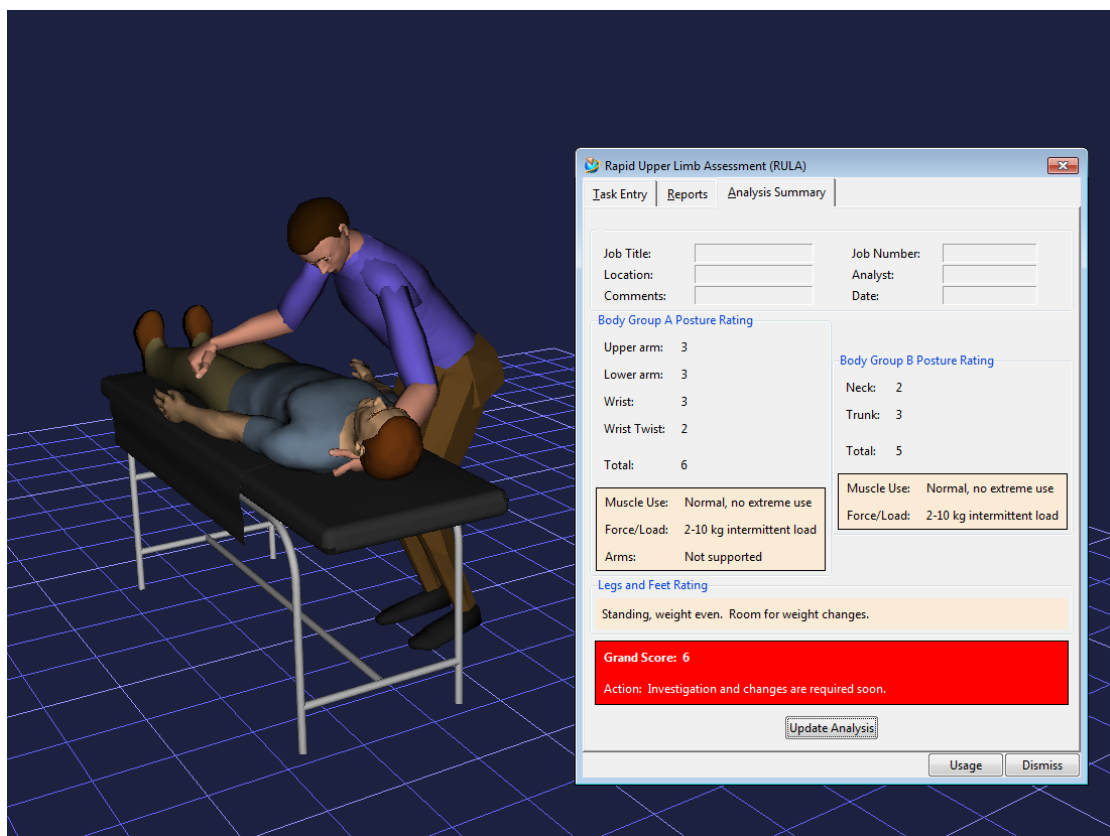
Fig. 80. Task 1, male 6.
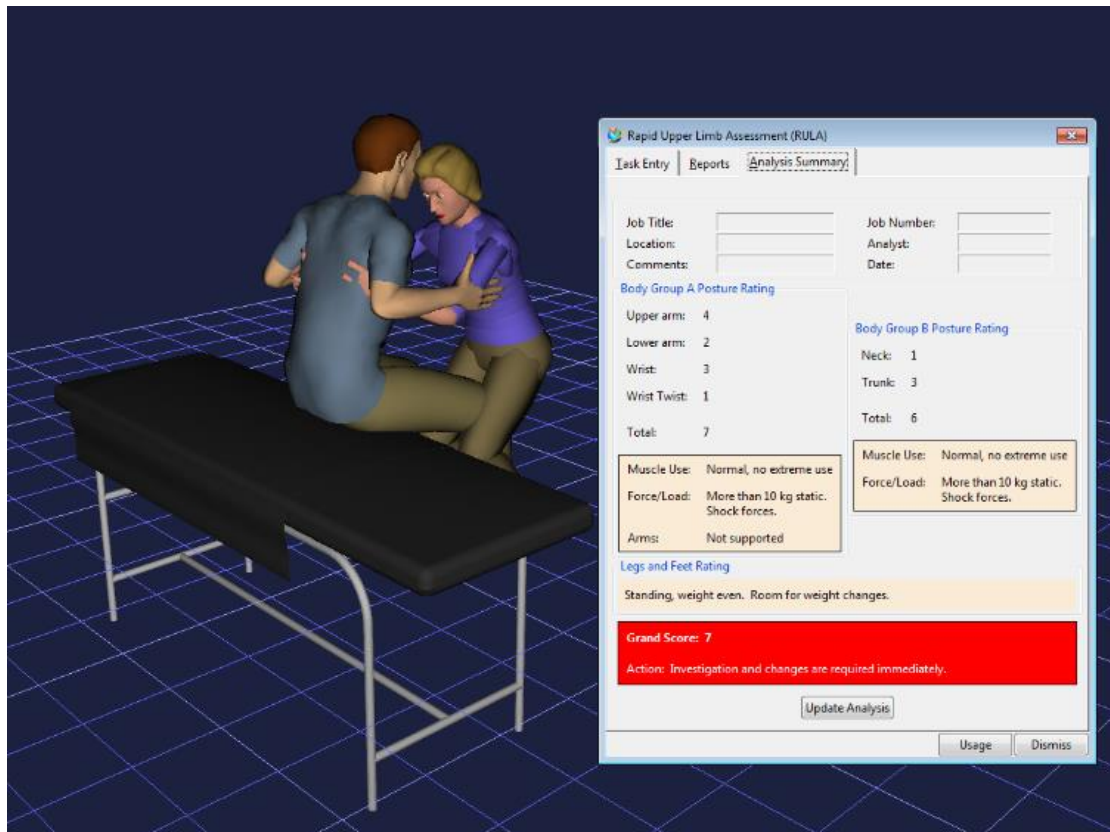
Fig. 81. Task 2, female 1.
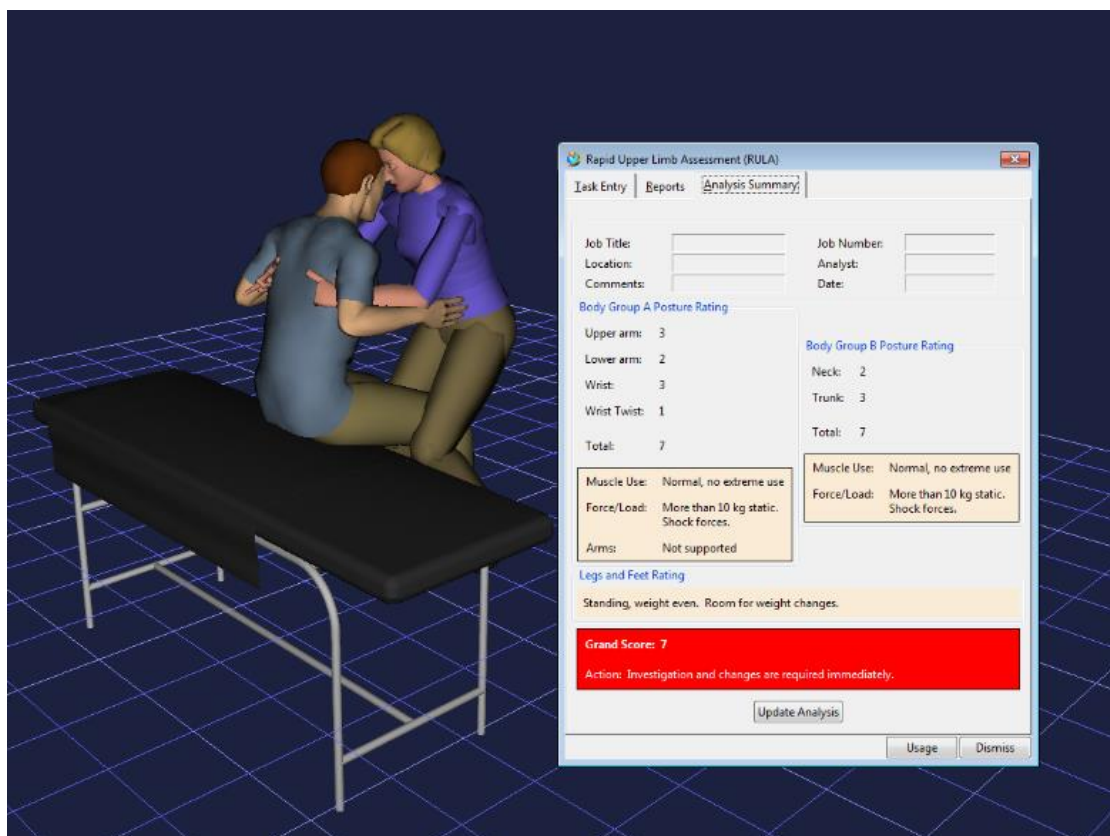
Fig. 82. Task 2, female 2.
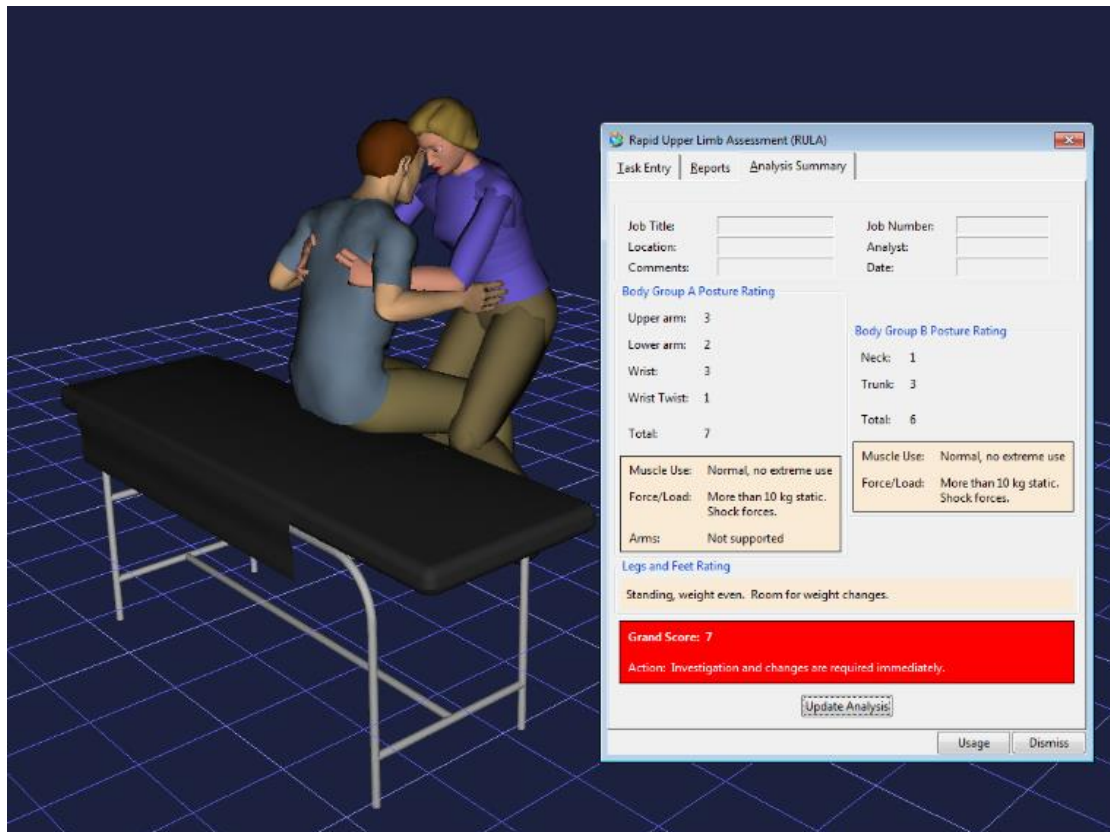
Fig. 83. Task 2, female 3.
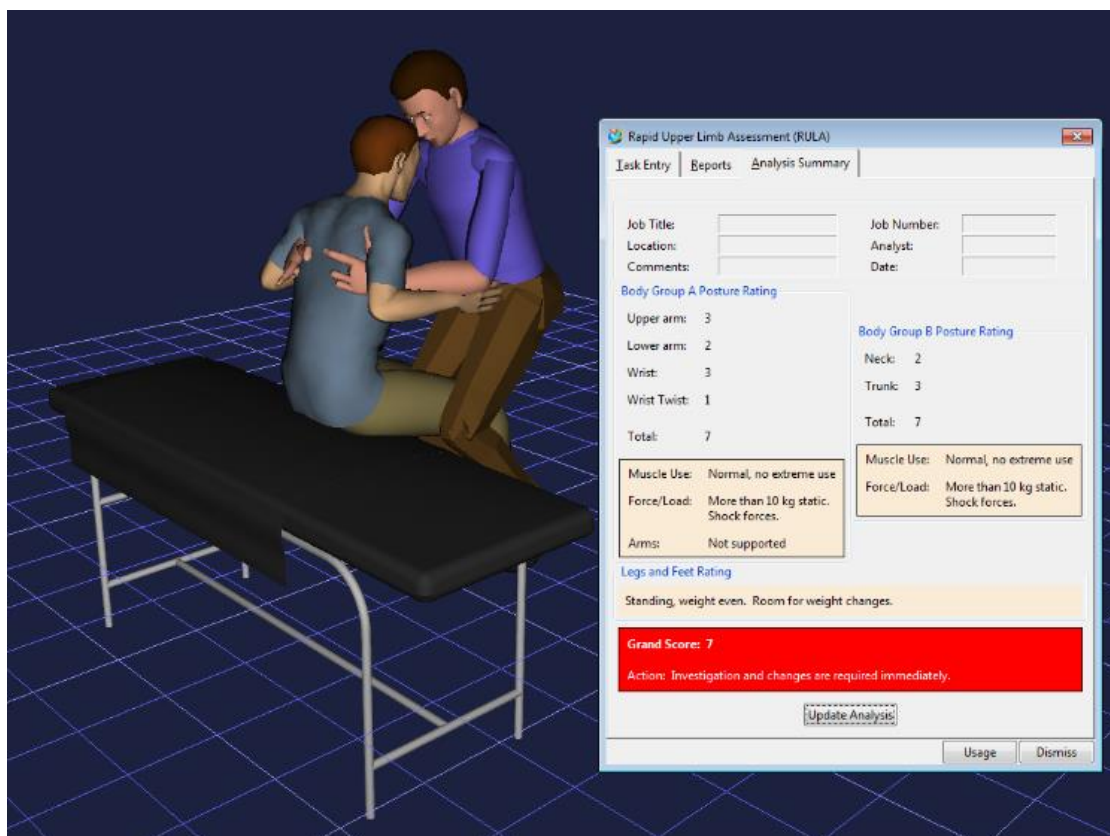
Fig. 84. Task 2, male 4.
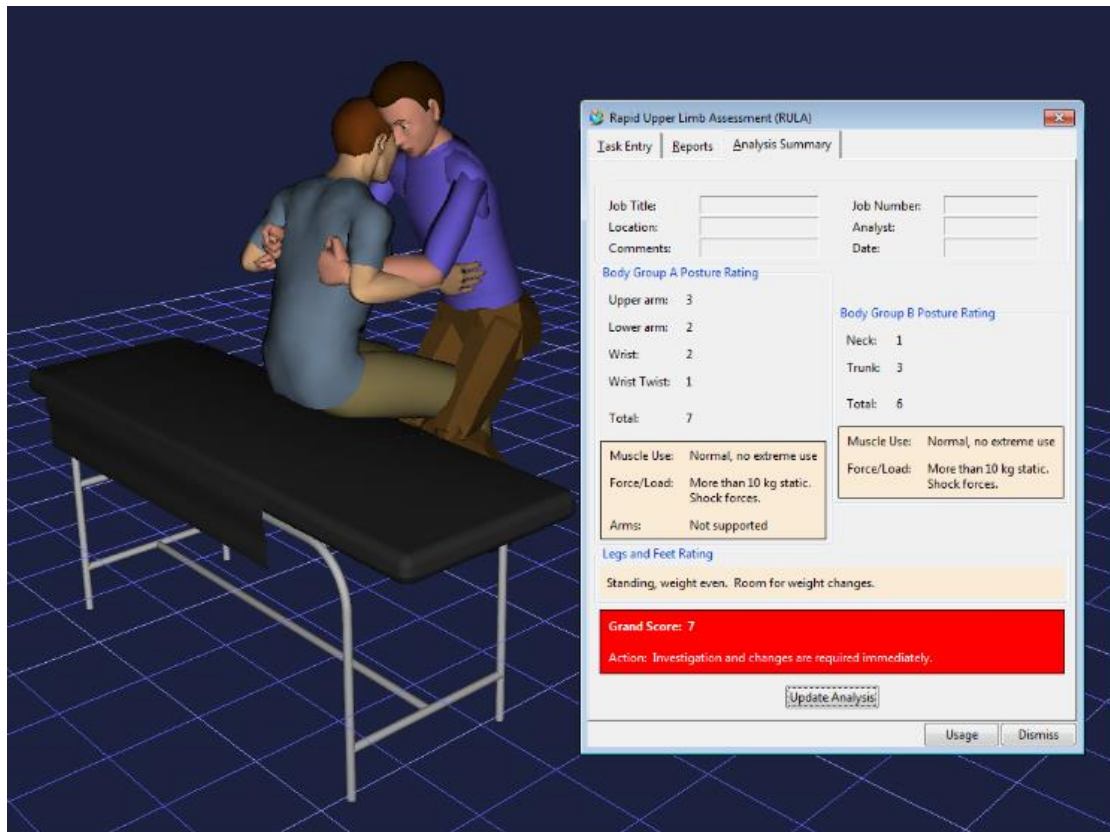
Fig. 85. Task 2, male 5.

*Fig. 86. Task 2, male 6.*

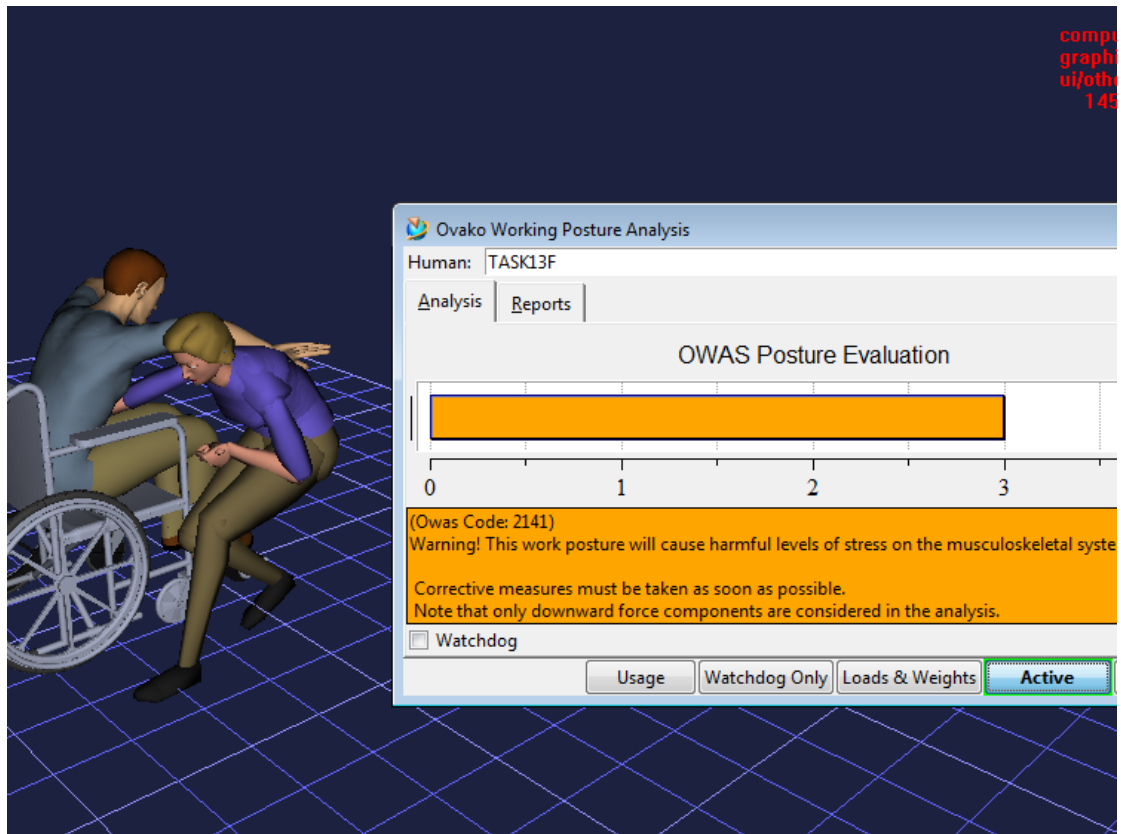*Fig. 87. Task 3, female 1.*

Fig. 88. Task 3, female 2.

Fig. 89. Task 3, female 3.
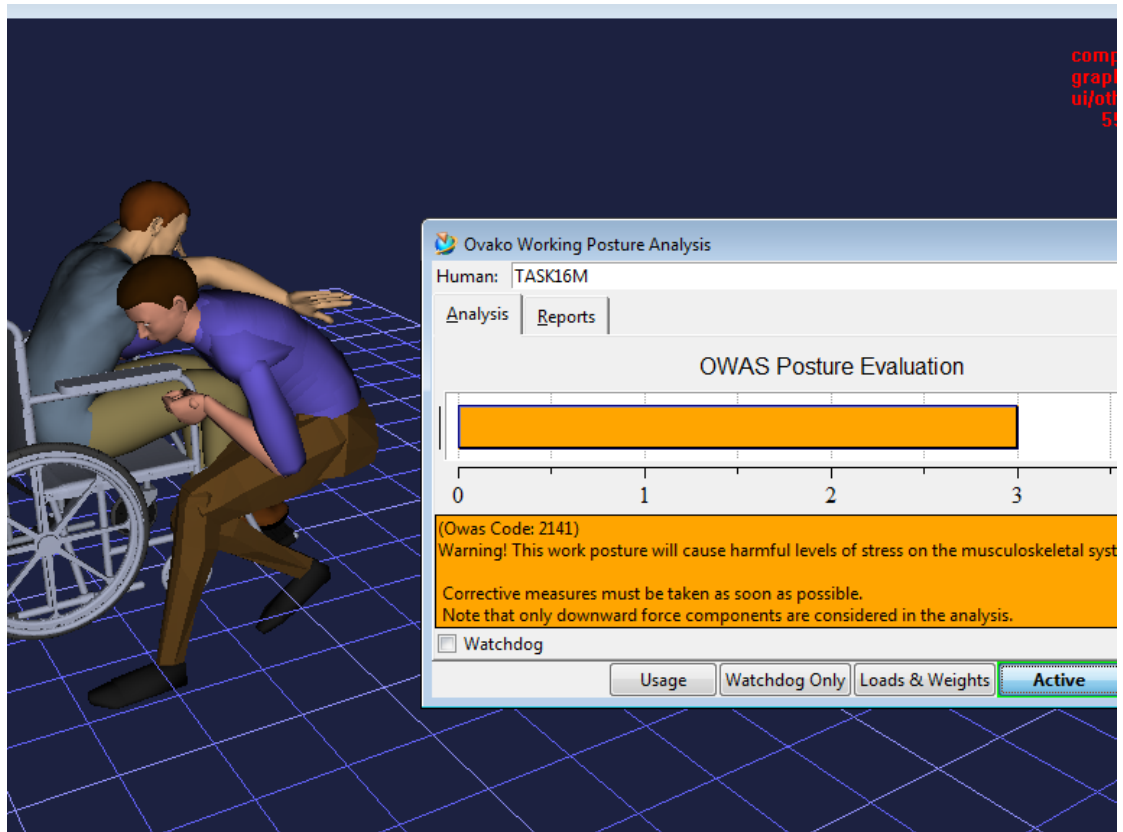

Fig. 90. Task 3, male 4.

Fig. 91. Task 3, male 5.


Fig. 92. Task 3, male 6.

Fig. 93. Task 4, female 1.

Fig. 94. Task 4, female 2.

Fig. 95. Task 4, female 3.

Fig. 96. Task 4, male 4.

Fig. 97. Task 4, male 5.

Fig. 98. Task 4, male 6.

10.6.2 OWAS Results

Fig. 99. Task 1, persona 1.

Fig. 100. Task 1, persona 2.
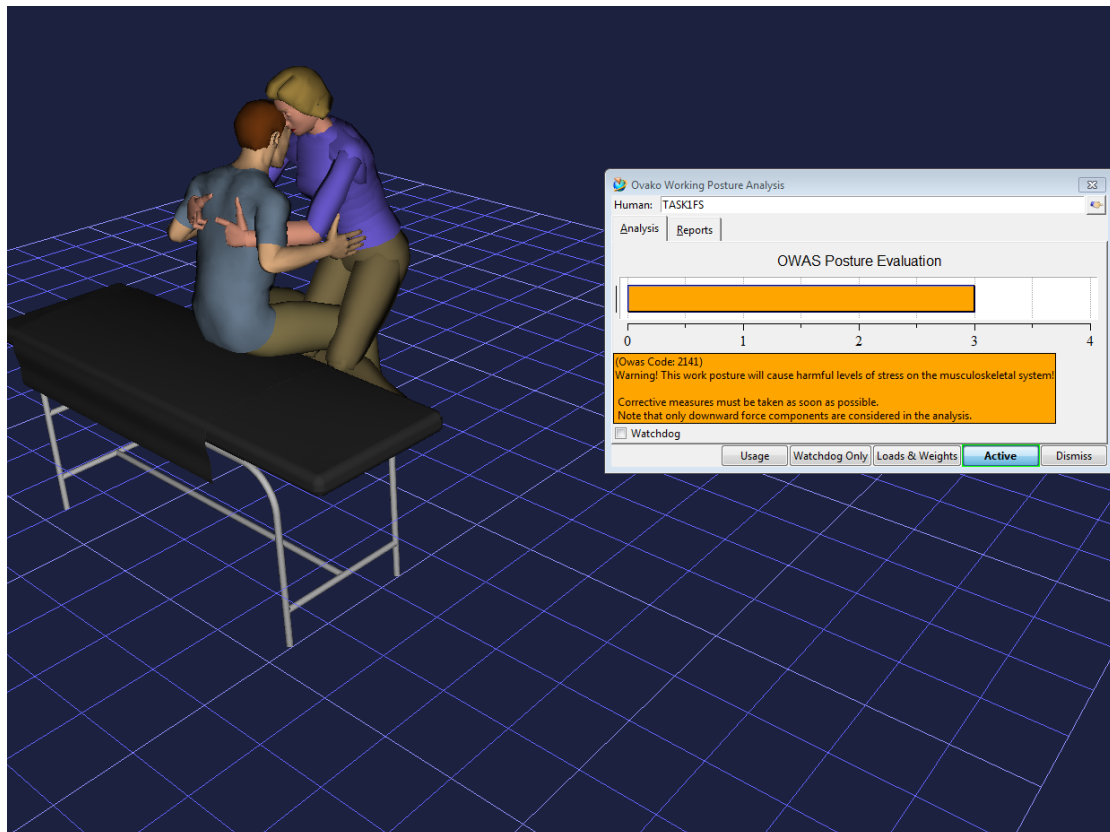
Fig. 101. Task 2, persona 1.

Fig. 102. Task 2, persona 2.
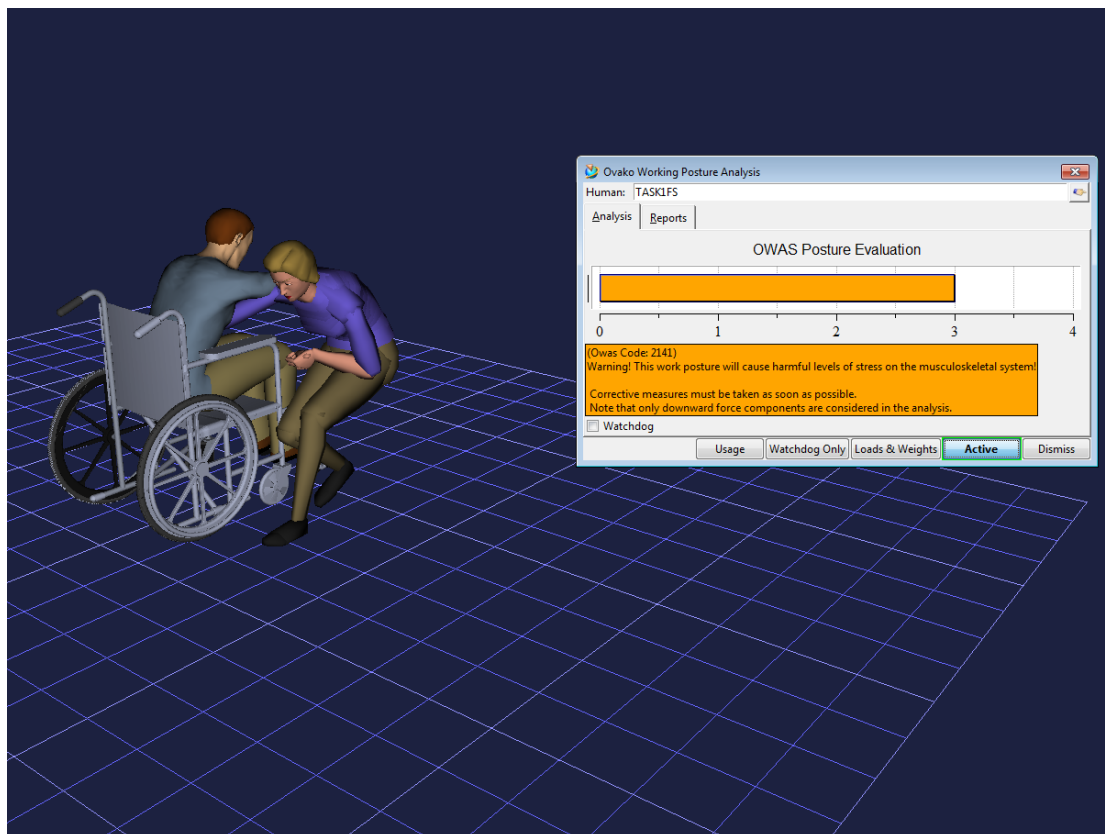
Fig. 103. Task 3, persona 1.
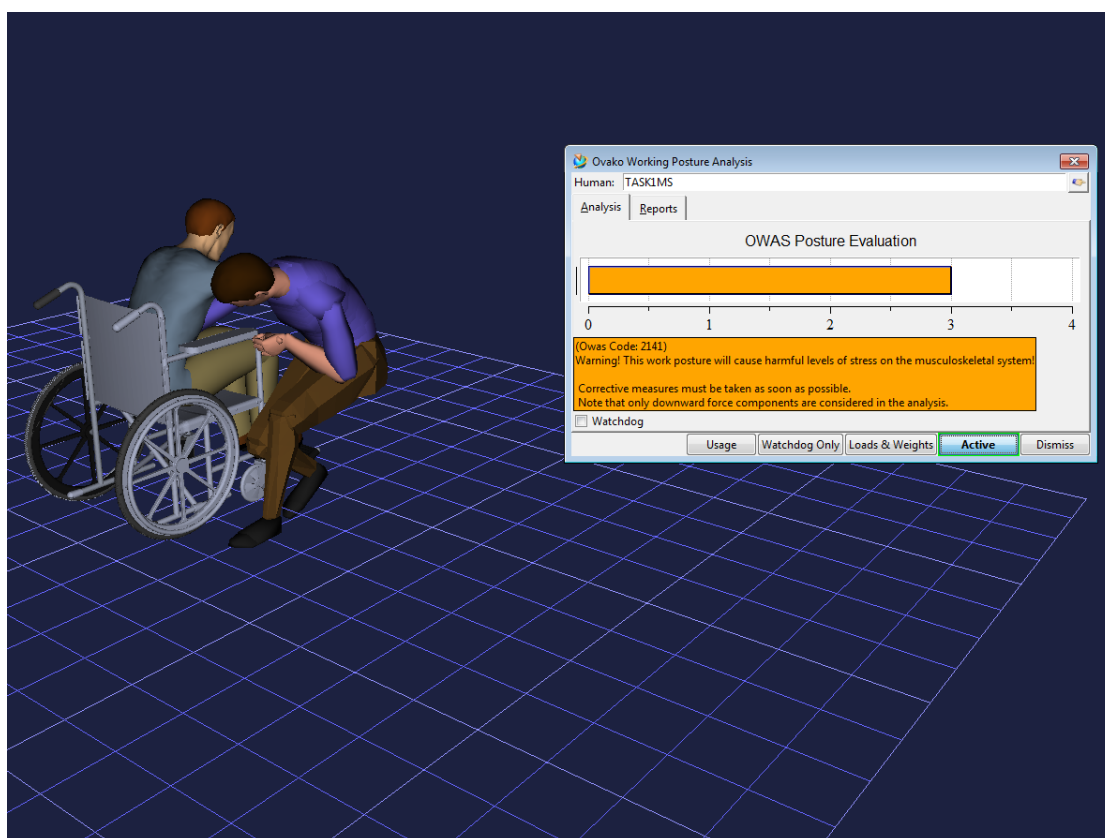
Fig. 104. Task 3, persona 2.
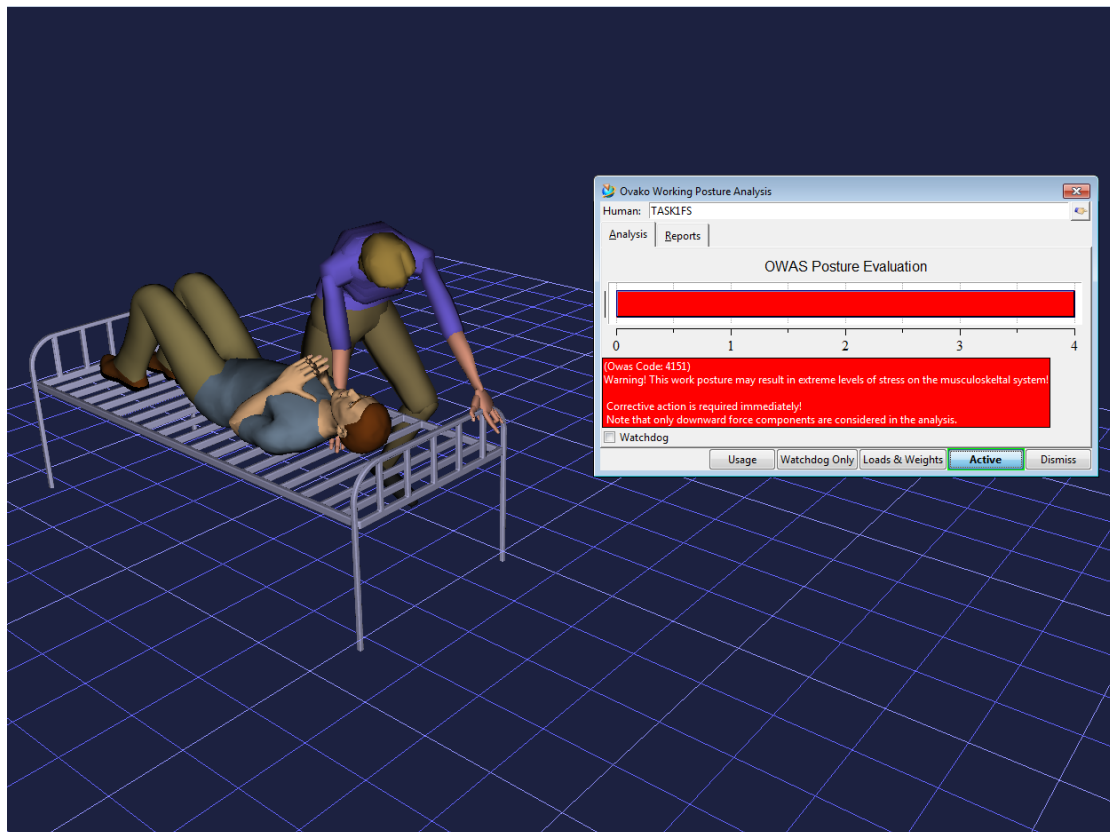
Fig. 105. Task 4, persona 1.
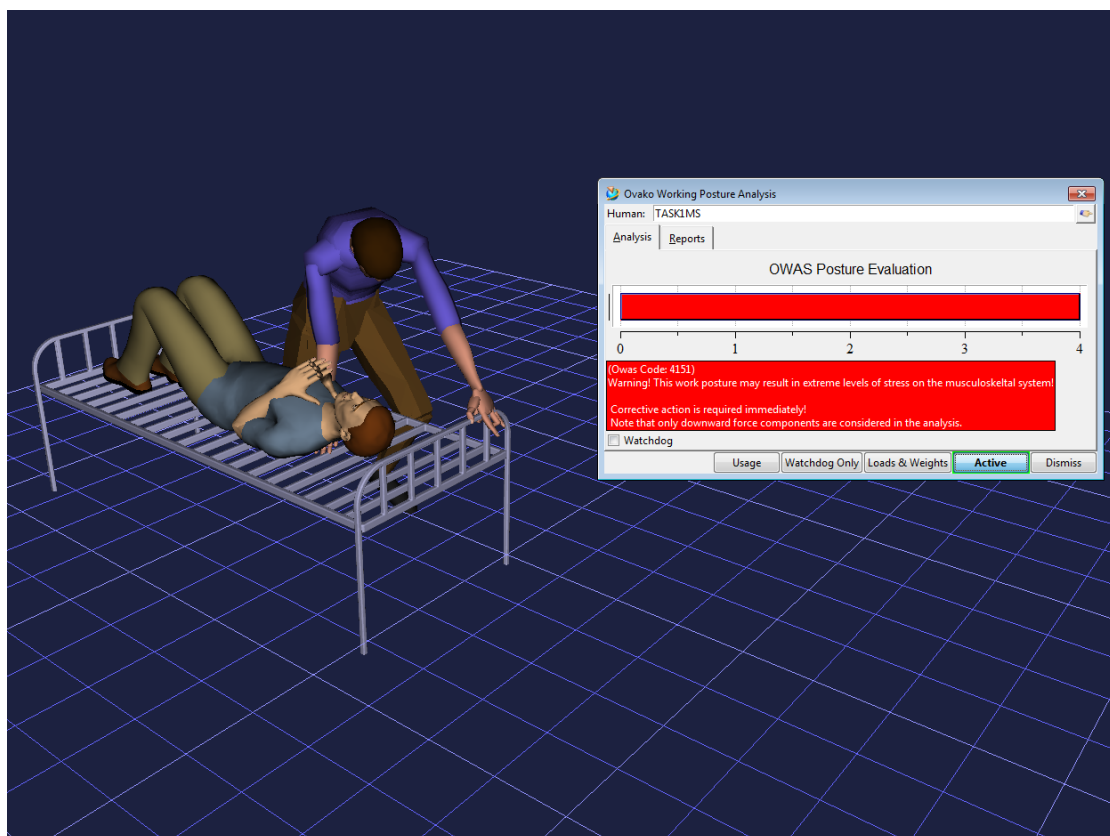
Fig. 106. Task 4, persona 2.
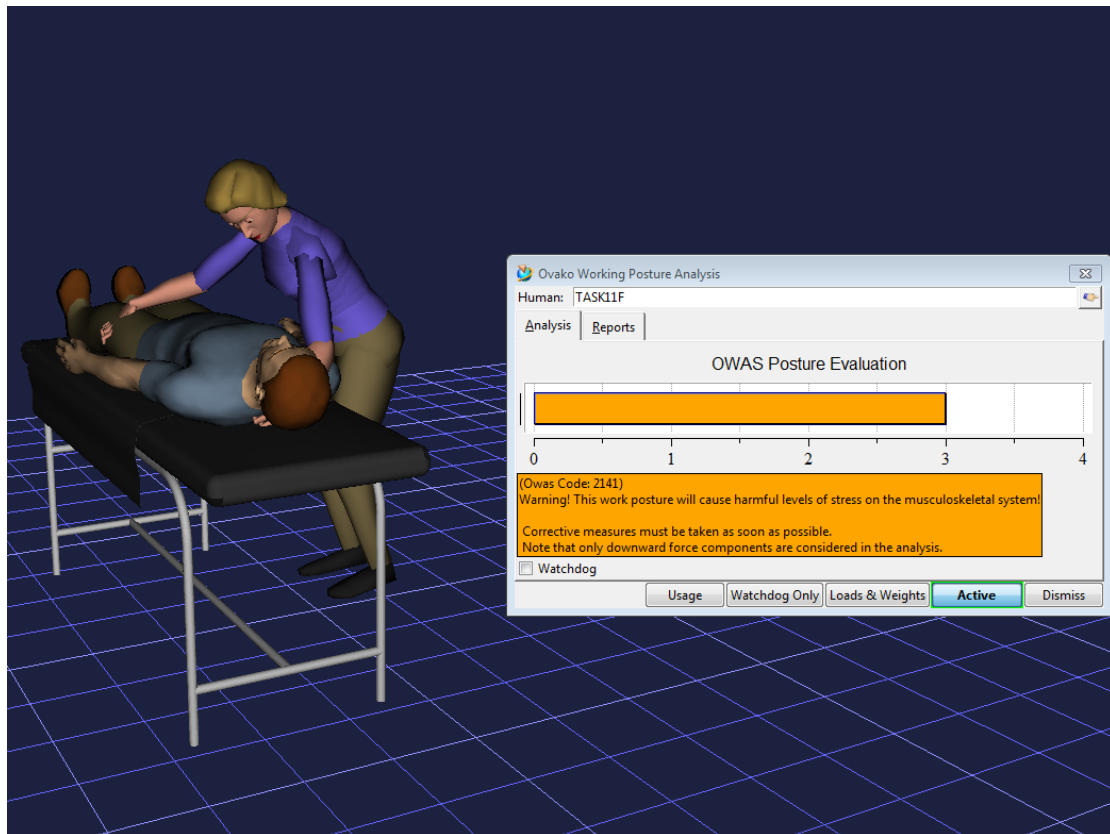
Fig. 107. Task 1, female 1.
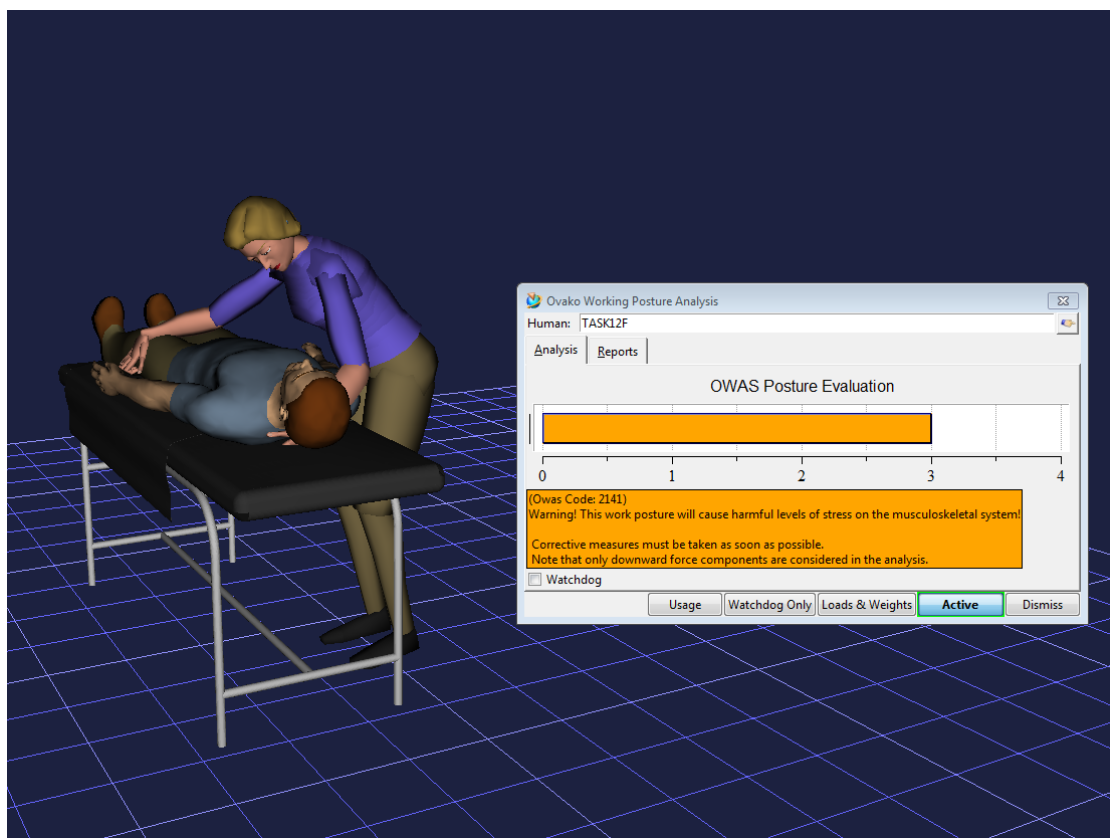
Fig. 108. Task 1, female 2.
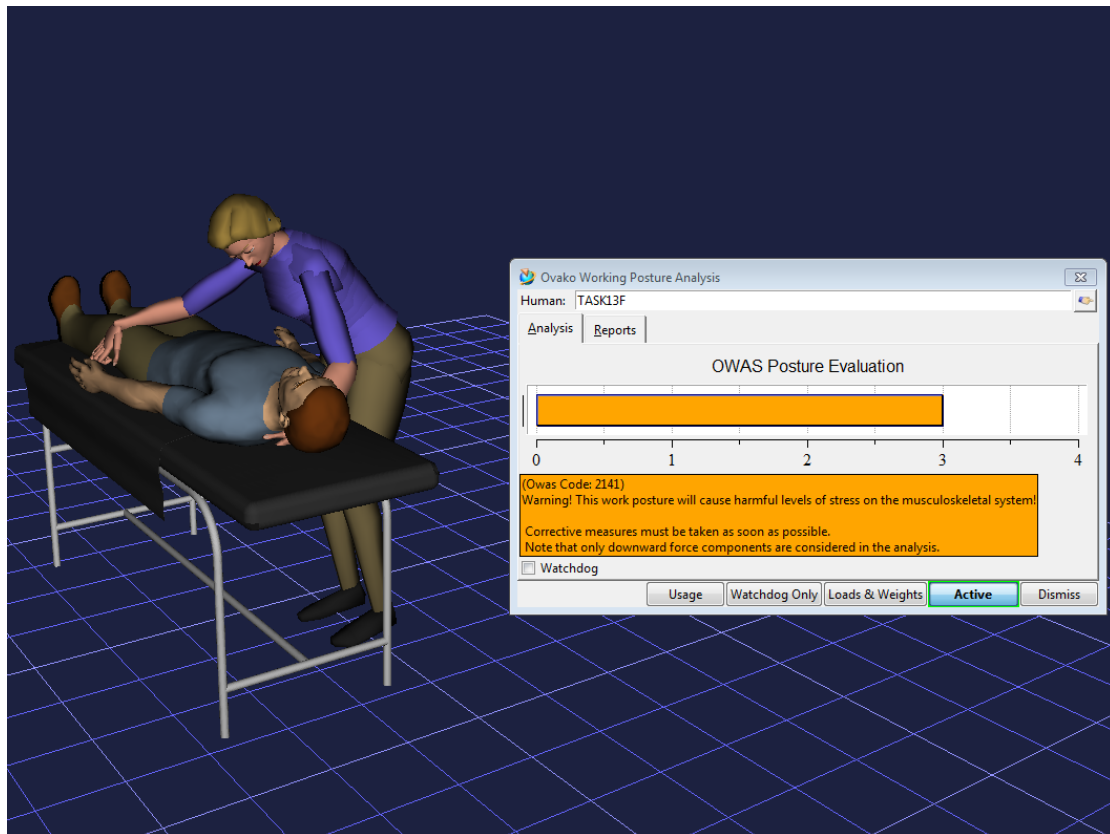
Fig. 109. Task 1, female 3.
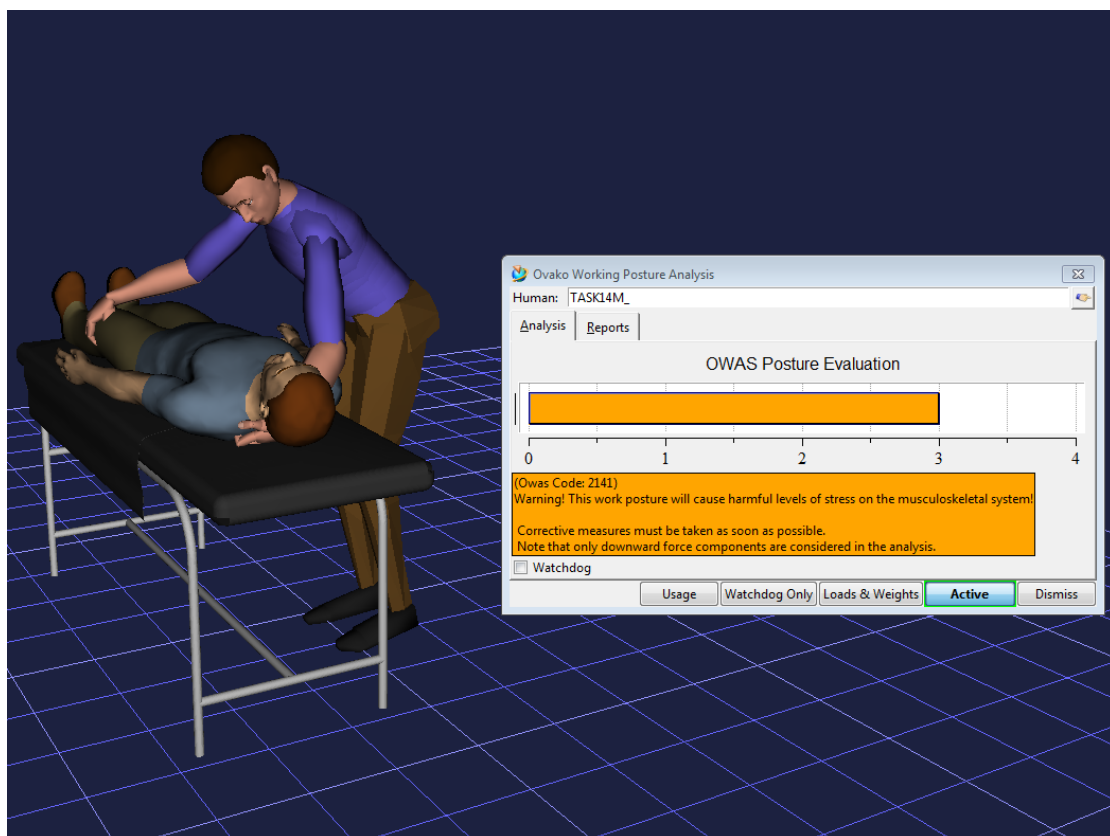
Fig. 110. Task 1, male 4.
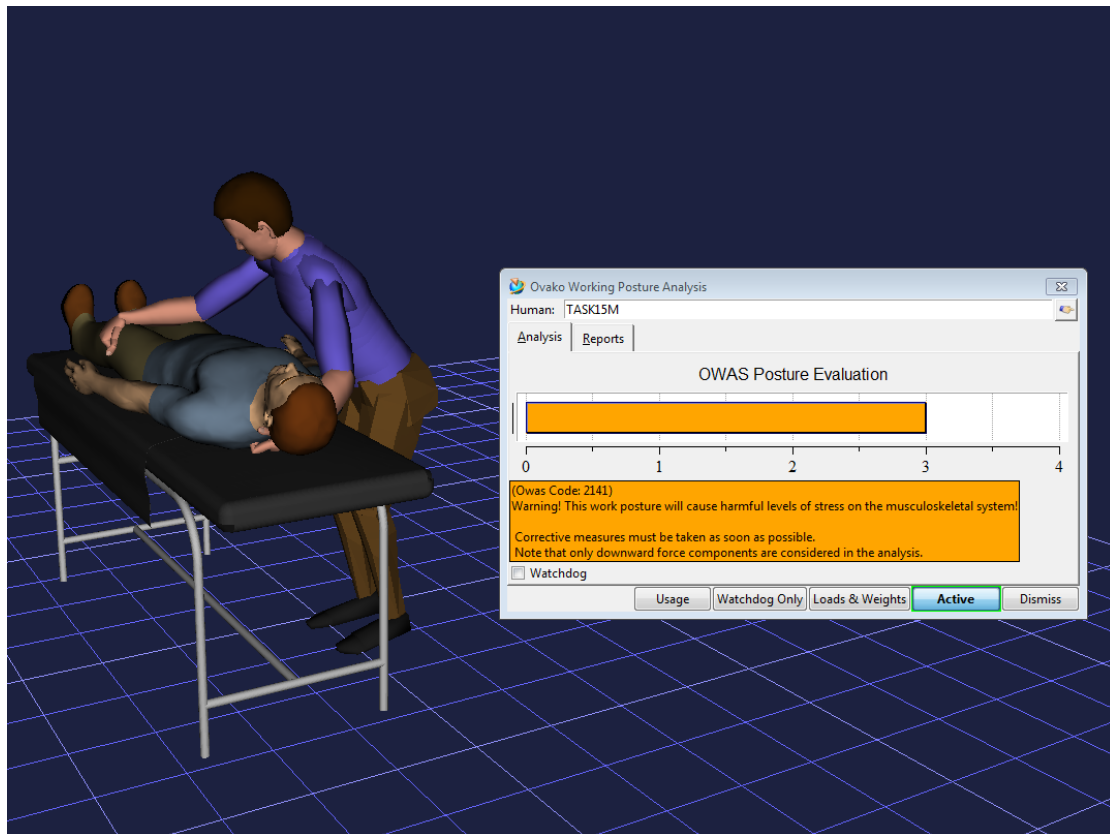
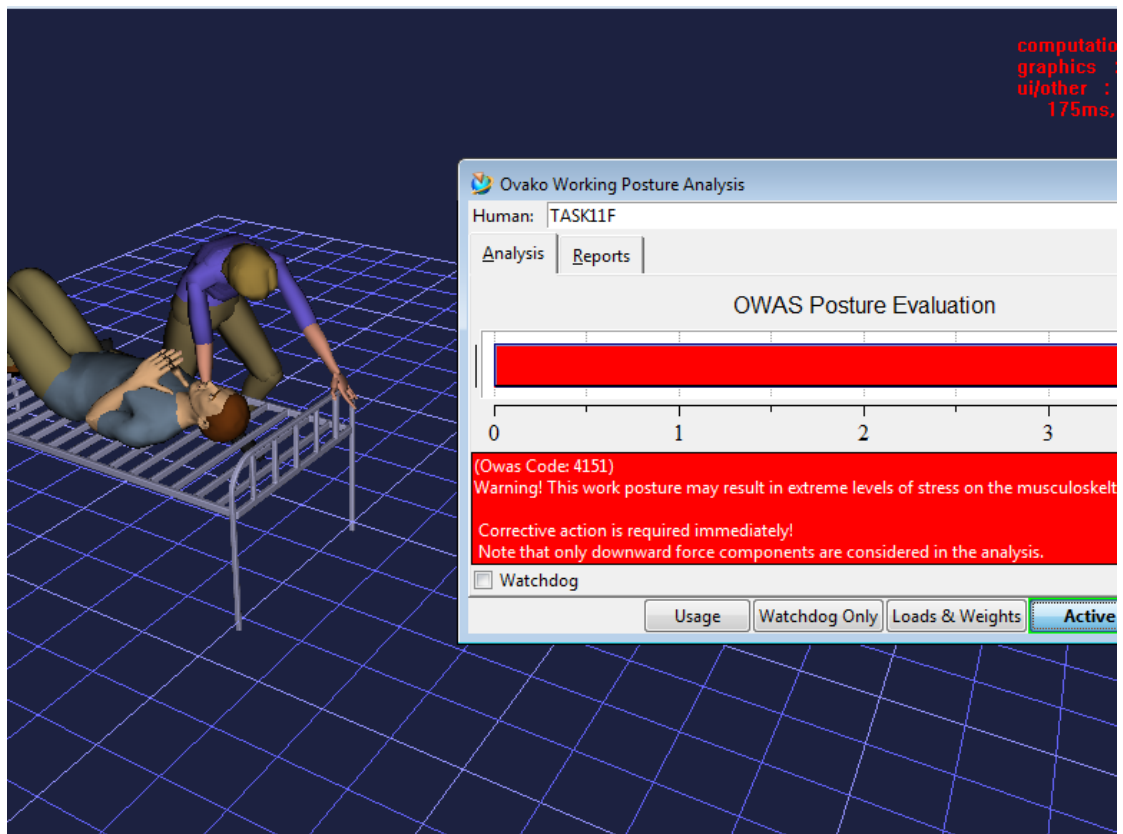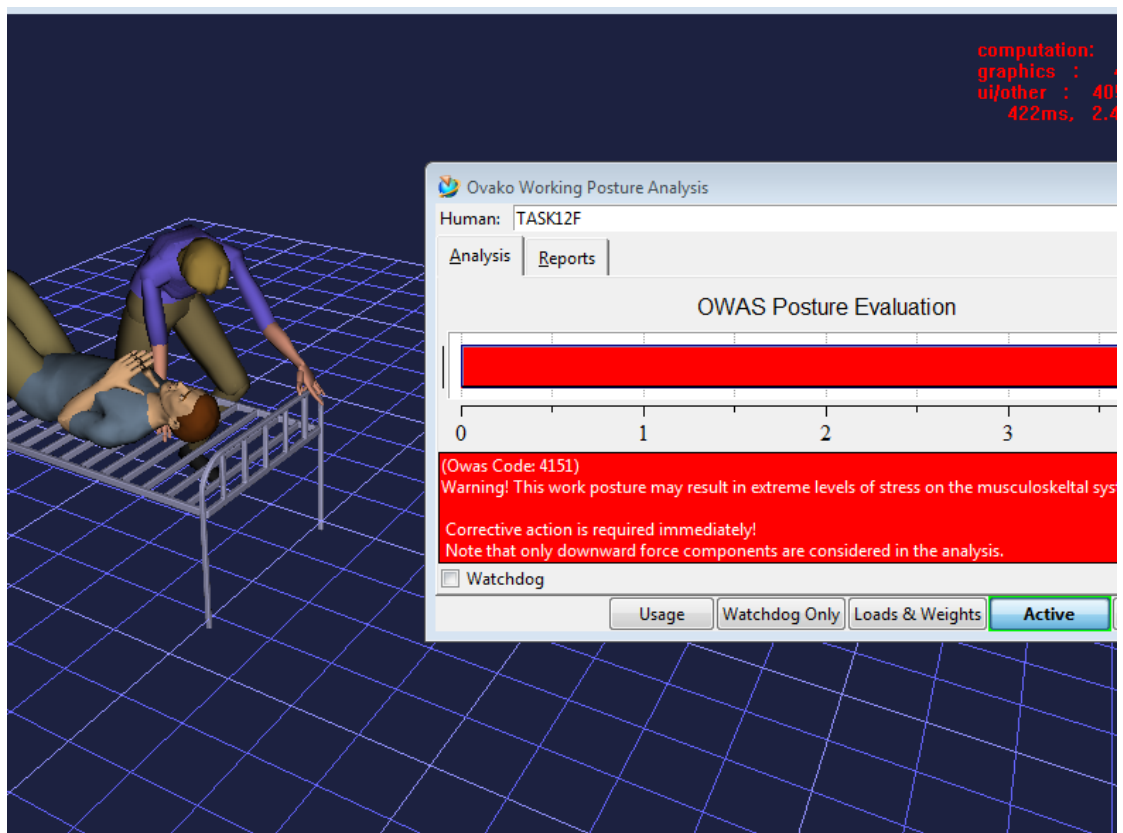*Fig. 111. Task 1, male 5.*
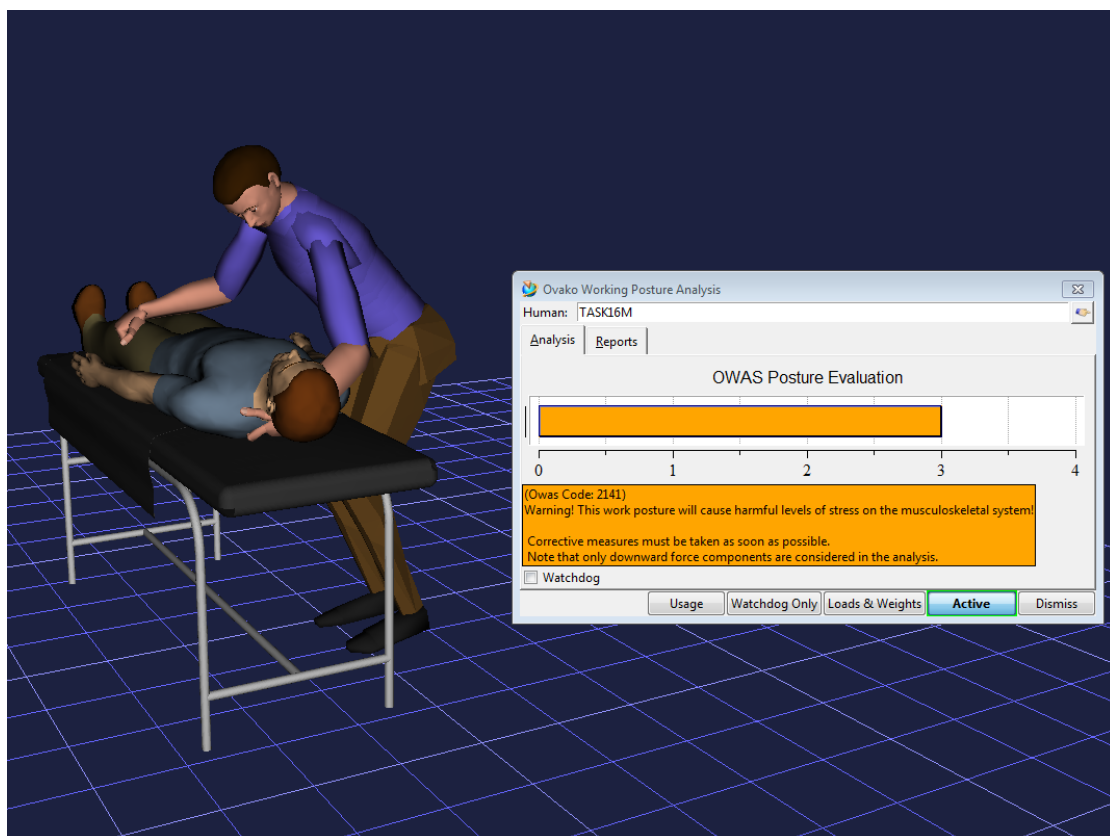
Fig. 112. Task 1, male 6.
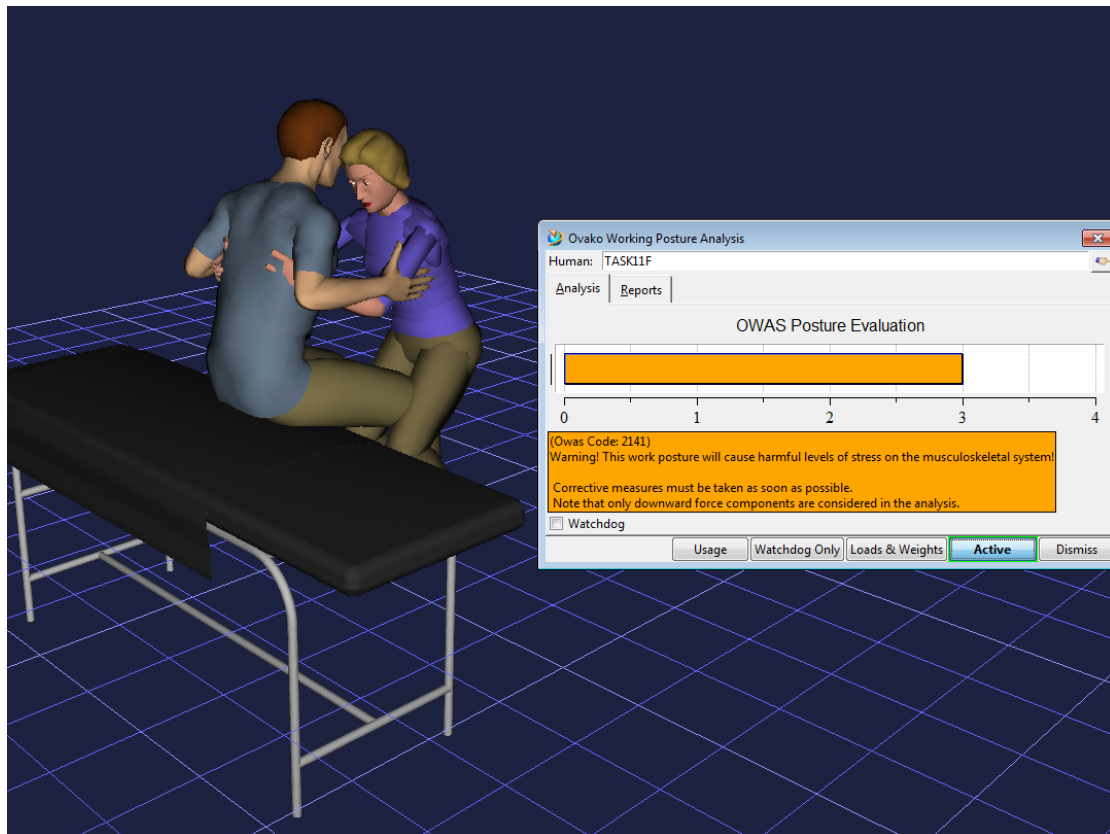
Fig. 113. Task 2, female 1.
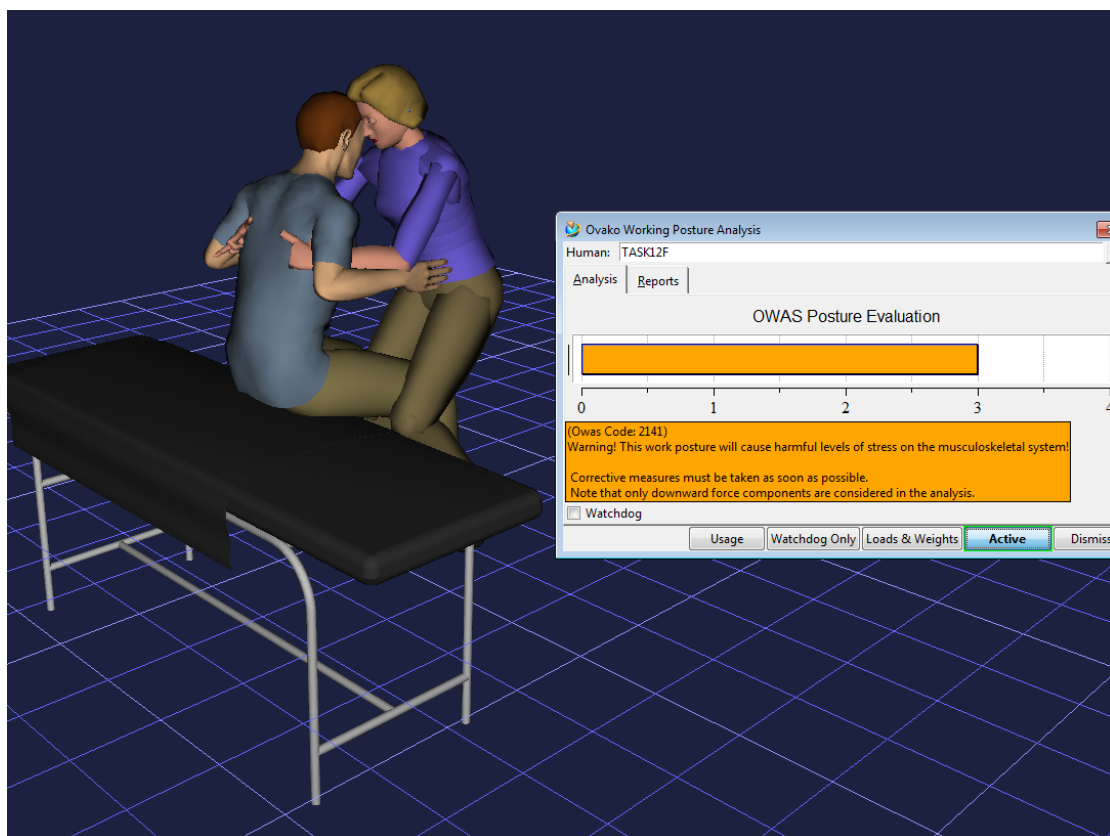
Fig. 114. Task 2, female 2.
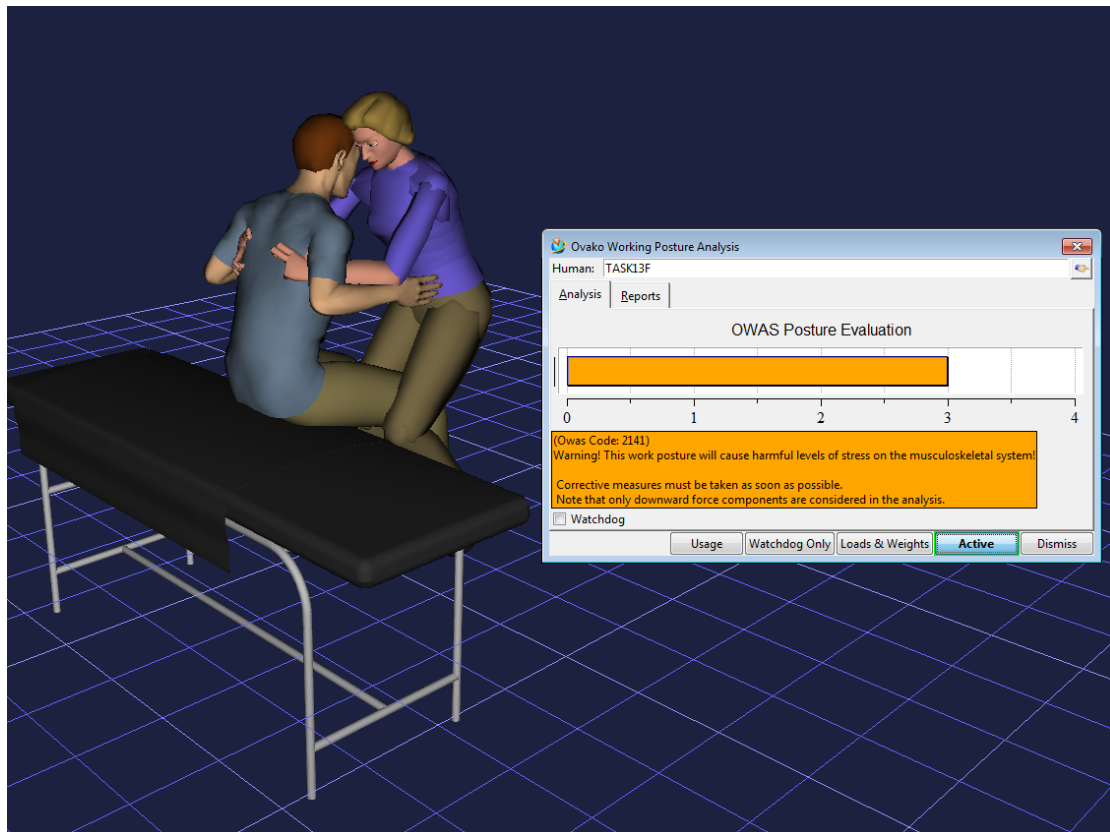
Fig. 115. Task 2, female 3.
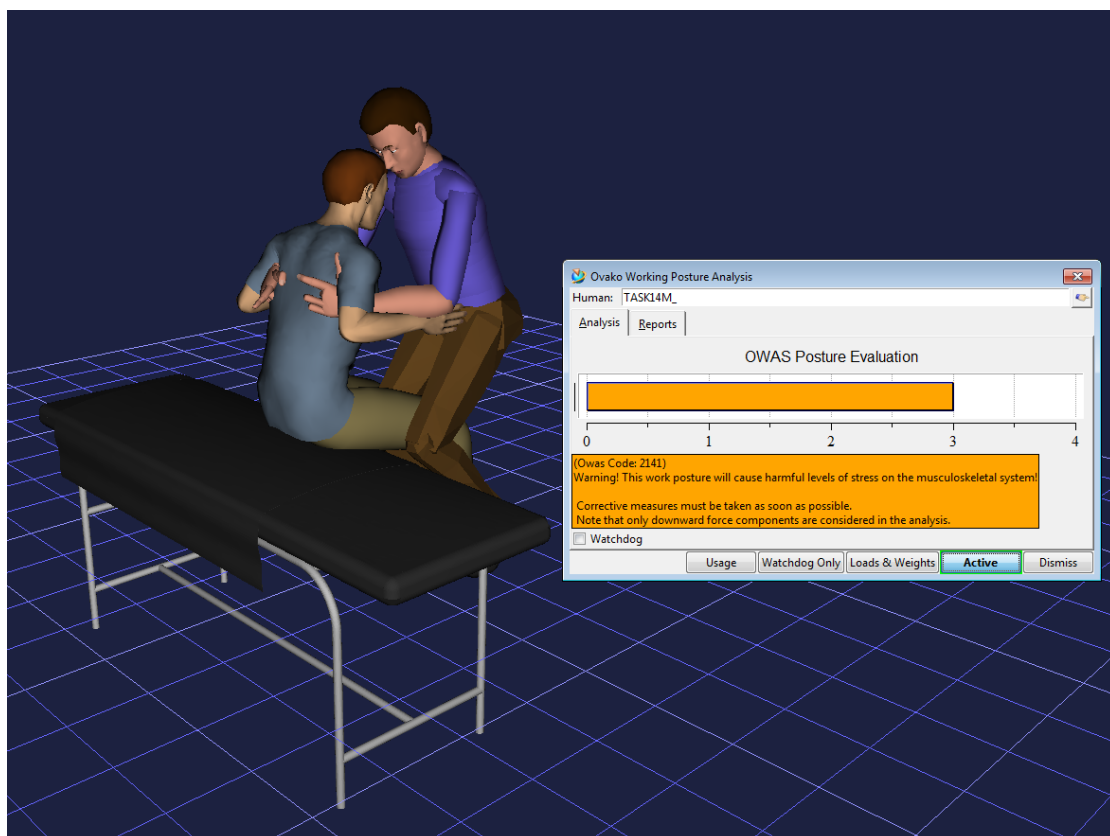
Fig. 116. Task 2, male 4.
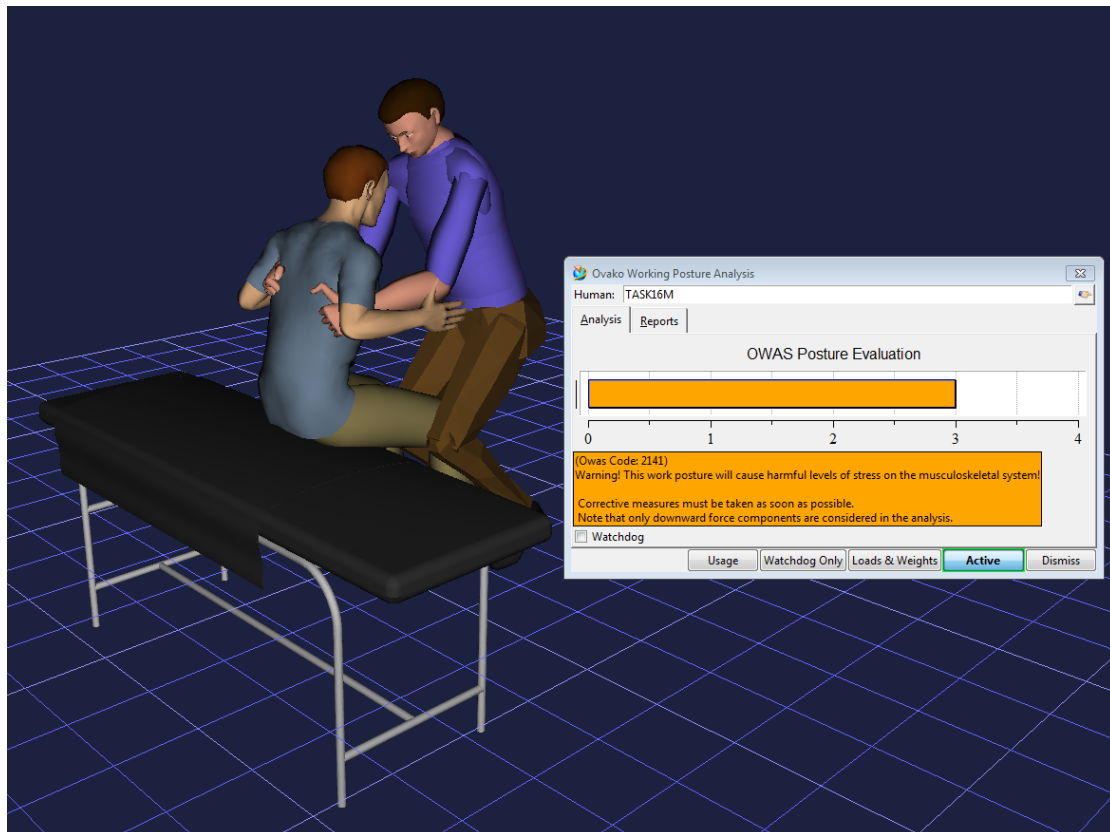
Fig. 117. Task 2, male 5.
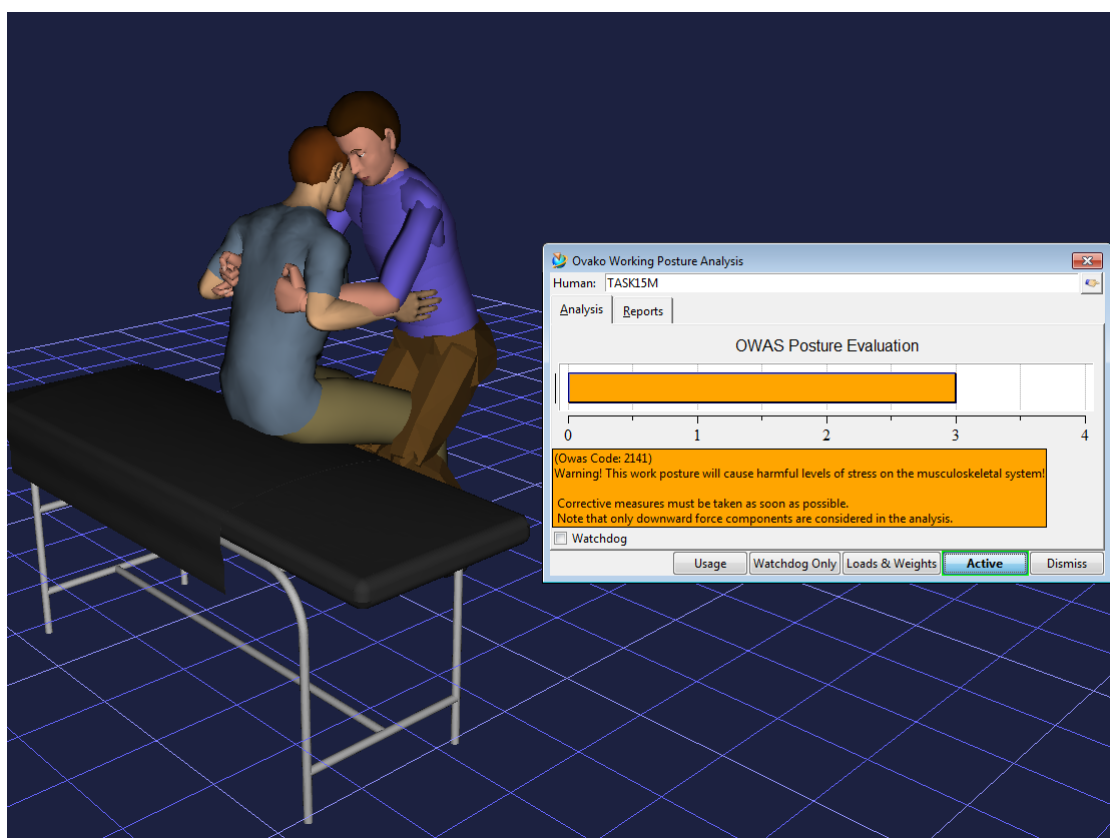
Fig. 118. Task 2, male 6.
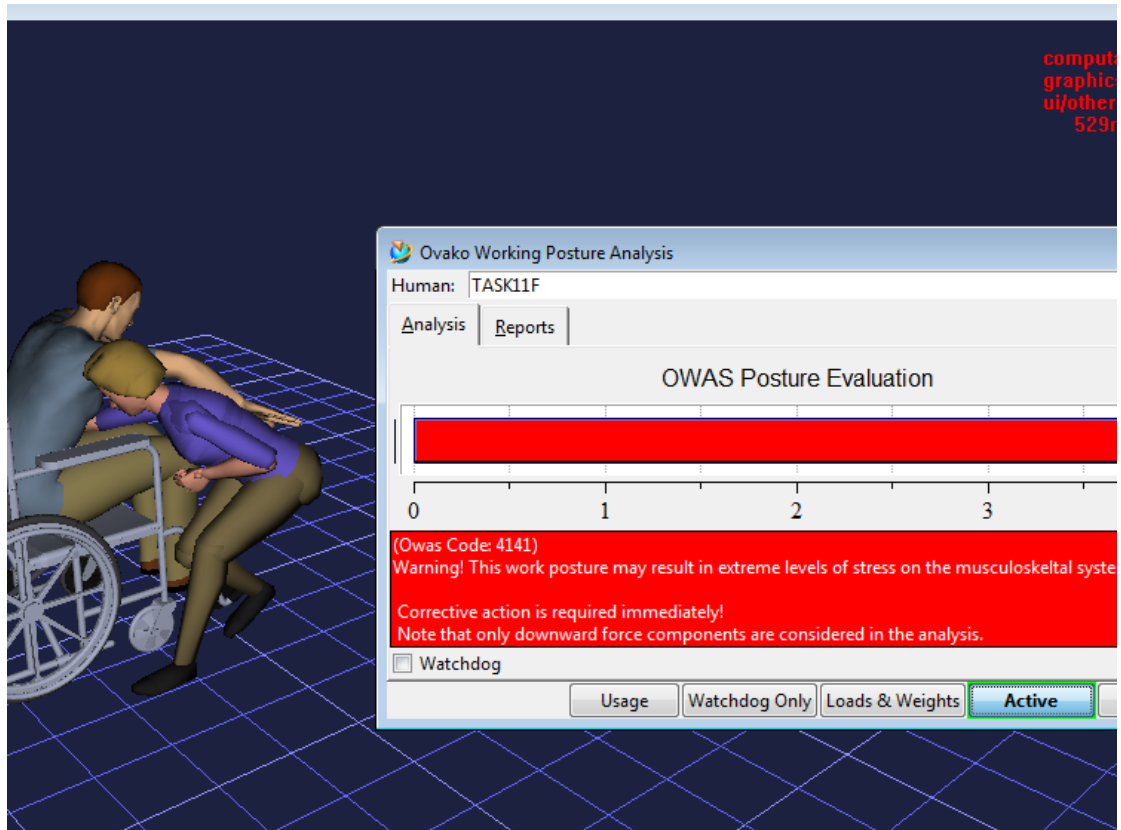
Fig. 119. Task 3, female 1.
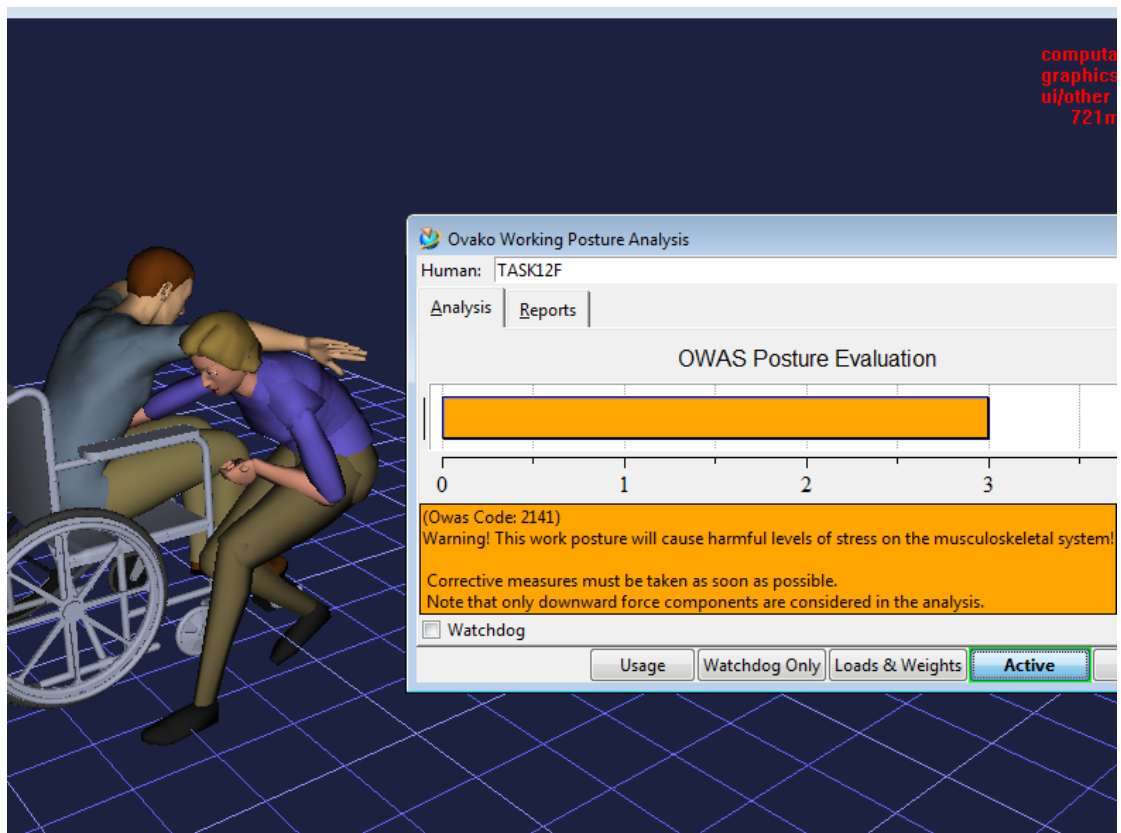
Fig. 120. Task 3, female 2.

Fig. 121. Task 3, female 3.
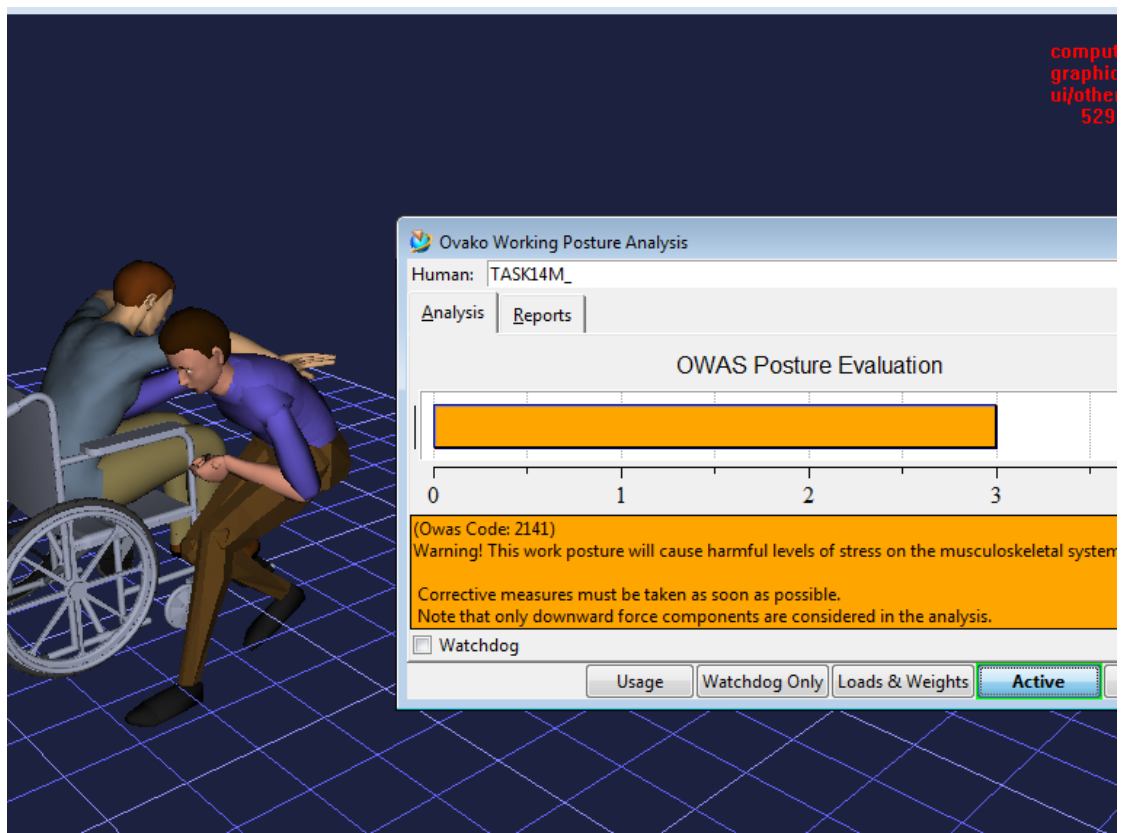
Fig. 122. Task 3, male 4.

Fig. 123. Task 3, male 5.
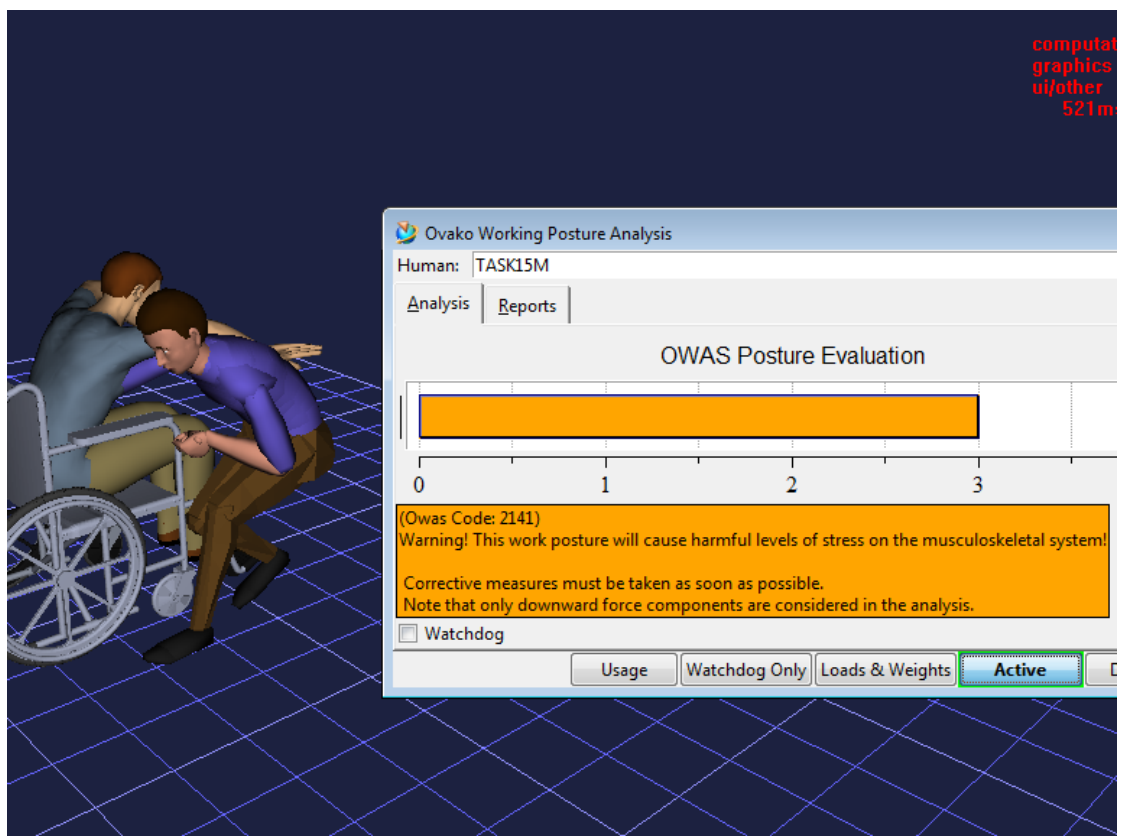
Fig. 124. Task 3, male 6.

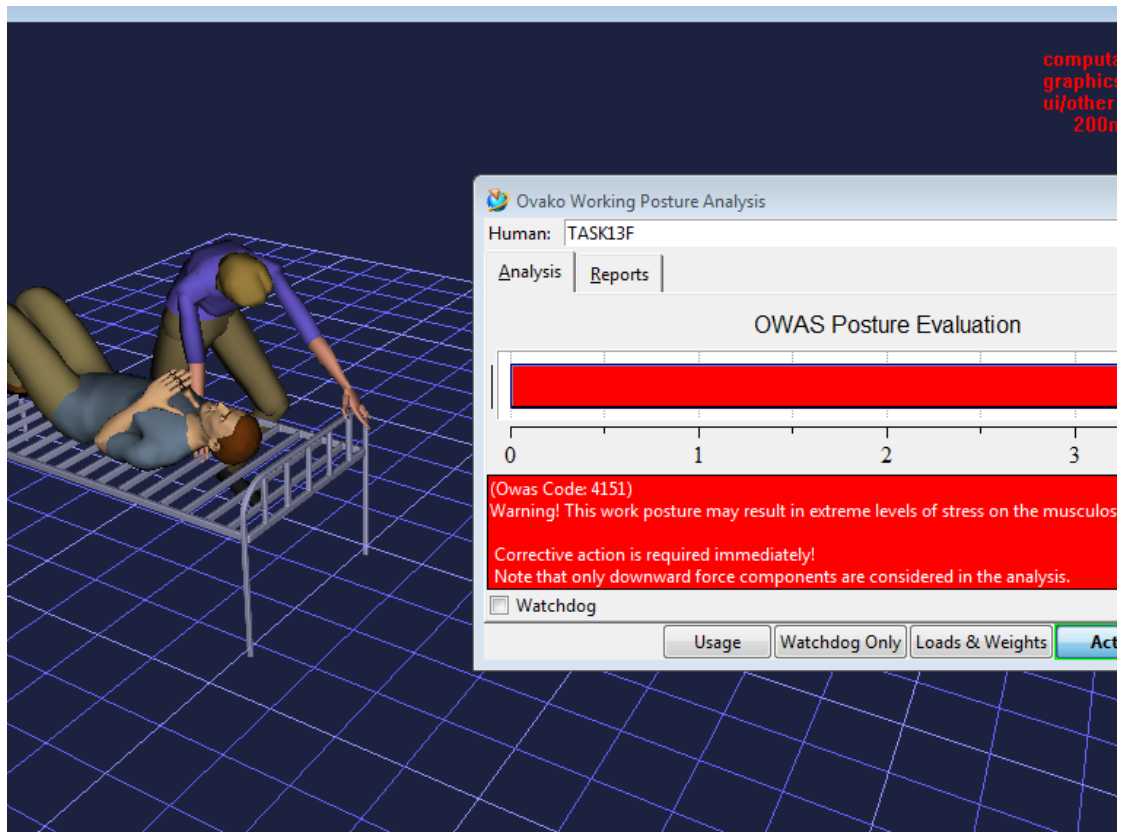*Fig. 125. Task 4, female 1.*

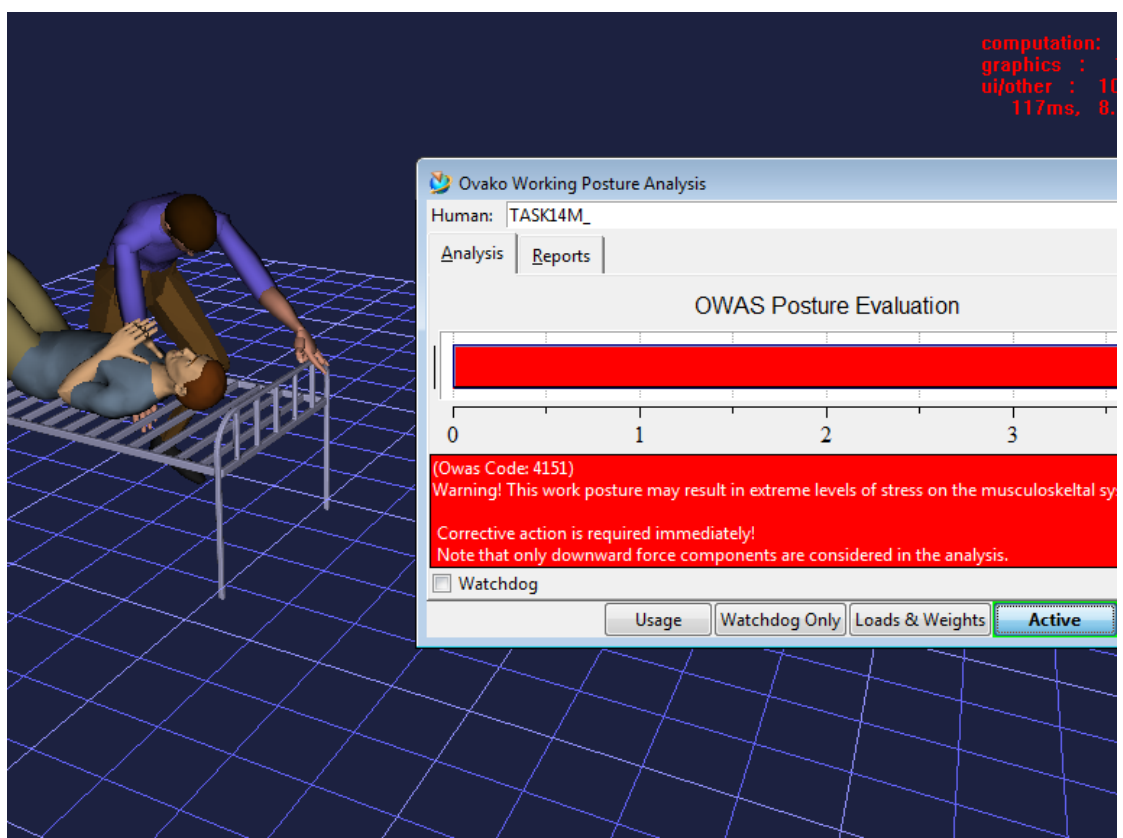*Fig. 126. Task 4, female 2.*
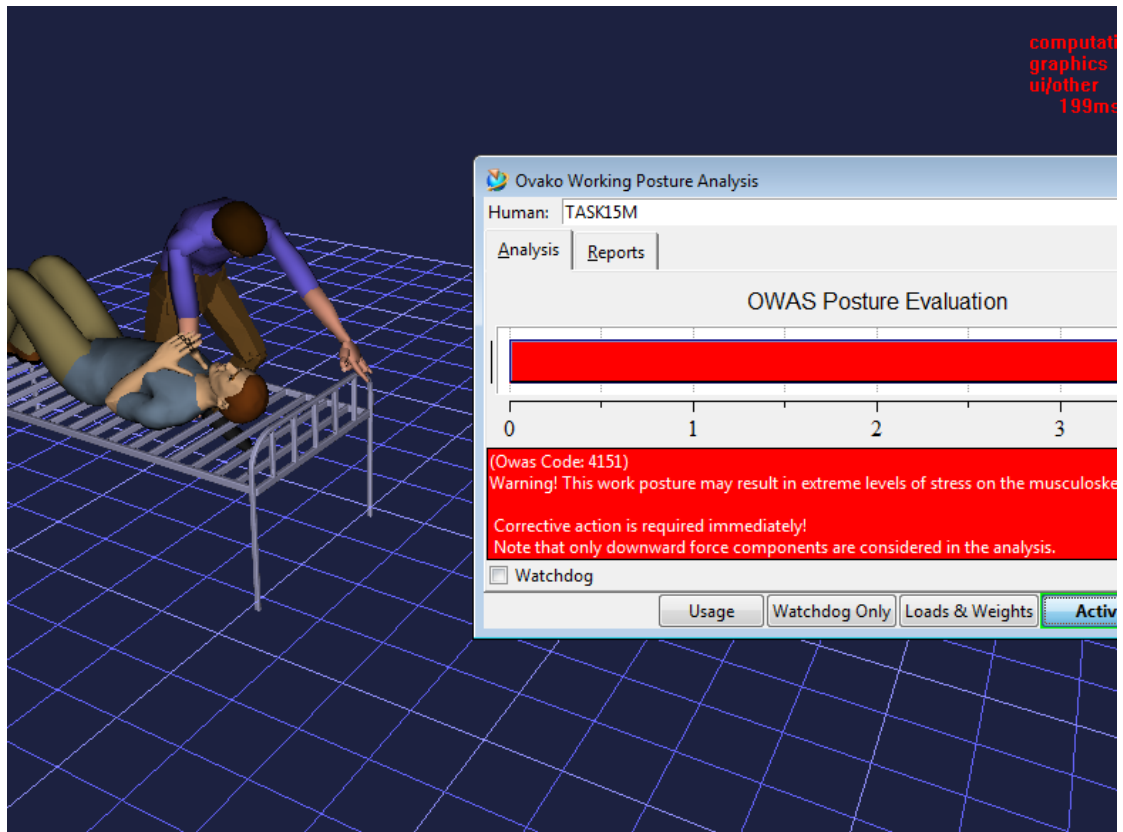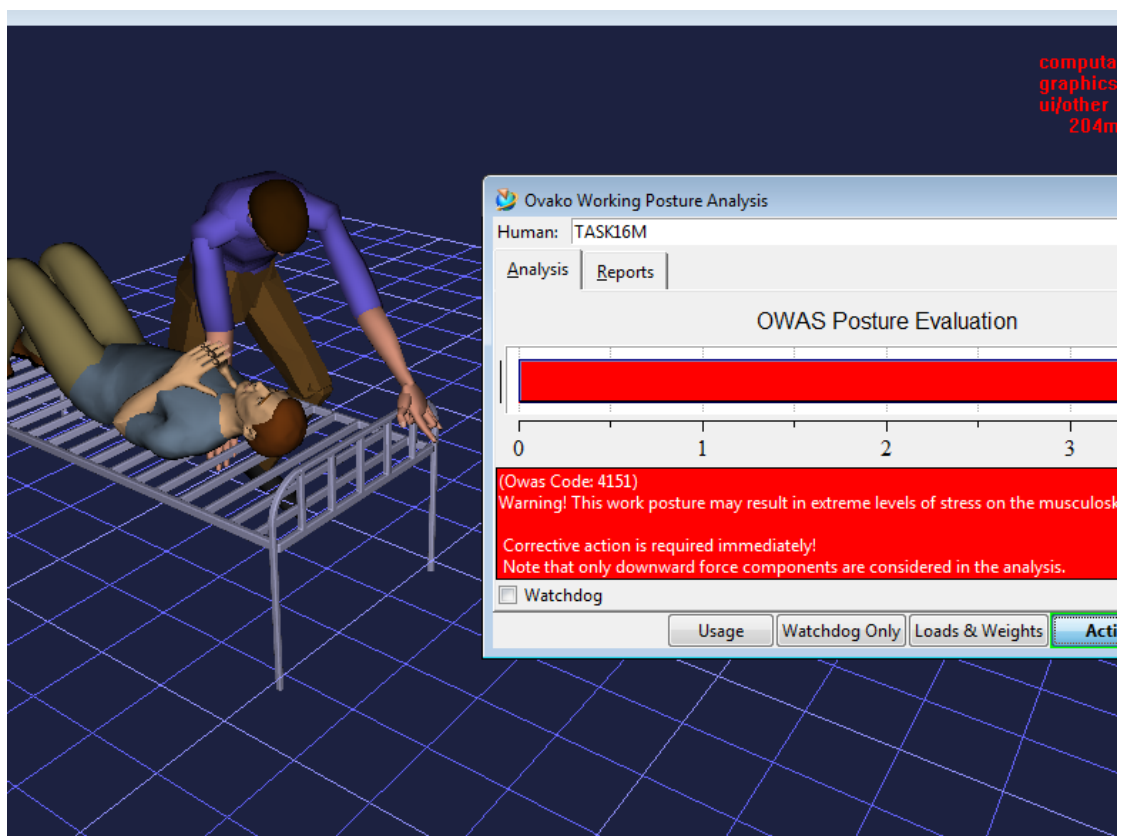
Fig. 127. Task 4, female 3.

Fig. 128. Task 4, male 4.

Fig. 129. Task 4, male 5.

Fig. 130. Task 4, male 6.