Assessment of Anthropometric Differences in the Design of Workstations: Case Studies of an Automotive Assembly Line

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Assessment of Anthropometric Differences in the Design of Workstations: Case Studies of an Automotive Assembly Line

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Abstract

The study investigates how the anthropometric differences in the postural analysis of workstations affect the ergonomic risk assessments. Three manual assembly operations from a car production line were selected as case studies. Postural analyses were performed through virtual manikins and selected operations were reproduced in physical in the lab. The program Siemens Teamcenter Visualization Mockup® was initially used to simulate the interaction of an "average-size" male worker with the workplace. Further analyses were carried out through a multibody model to verify the accessibility and postural comfort of different anthropometric percentiles. Results demonstrate the importance of a postural assessment also for limiting users, especially in case the assembly line cannot be adjusted to the operator's anthropometry, and the benefit of easy-to-use simulation tools to assist the ergonomist in the workstations design and to ensure the required comfort for all operators.

Keywords: Digital human modelling; Ergonomics; Postural analysis; Reachability; Comfort evaluation

INTRODUCTION

Digital Human Models (DHM) are an effective tool for proactive ergonomics analysis. Designers may position and manipulate an avatar (or virtual human) within the simulated work environment and explore potential advantages and disadvantages of different design configurations even before the workstation exists and physical tests are viable [1]. The importance and usefulness of DHM to facilitate the design process and to assess biomechanical risk factors from the early stages of design have been discussed extensively in the literature. Simulated ergonomics evaluations have shown reliable results for various work task scenarios [2-5], showing that DHM may indeed provide useful indicators for ergonomics and assist the analyst in designing or redesigning more comfortable workstations.

One of the principal uses of DHM programs has been the prediction of operators' reach and clearance capability. The evaluation of reach envelopes and collision points depends upon the anthropometry of the manikin employed for the simulation and the use of many different manikins, that are representative of the size variability of the population of interest, is usually required for accurate estimates. In addition, the position of the manikin in the work environment also affect results. The posture of the manikin is either manipulated directly by the analyst or generated using an inverse kinematics algorithm. Accurately reproducing human body posture and motion has been proven to be very critical in DHM and highly time consuming [6-7].

In the recent decades, several software programs have been developed. With the increasing of computer power, also the quality and the sophistication of the DHM programs have kept increasing to meet the demand of industries and researchers [8]. Nonetheless, simpler tools and guidelines for easy-to-run postural checks on potentially critical working points may support the analyst in early ergonomics assessments during the design phase [9]. Computed postural angles can be used to verify compliance with the recommendation of the international technical standards [10-11] or used as input data for calculating ergonomics risk indexes [12-16].

The aim of this work is to investigate the anthropometric differences in the postural analysis of workstations and the potentiality of rapid screening tools to estimate the postural angles for the limiting percentiles in a given workplace. The discussed case studies were selected from the digital modeling of FCA production lines and a simple 2D multibody model was used for the postural assessment. The model, developed by FCA in cooperation with the academia [17], can run on a widespread program like Excel and does not require training in complex computer packages.

MATERIALS AND METHODS

Selection of case studies and preliminary analysis

The program Siemens Teamcenter Visualization Mockup® v11.2 was used for modelling the work environment of the assembly line. In this software environment, the tool JACK [18] is available for creating a 3D human model in order to investigate the interaction of the virtual operator with the workplace. Due to the time required to set up the simulation and position the manikin, it is common practice to limit the full simulation analysis to the “average worker”, that is the P50M (50th percentile) male manikin, even though reachability and clearance problems can be particularly critical for limiting users like very short female and very tall male operators.

Three specific assembling operations were then selected as potentially critical for the posture of the trunk and of the upper limbs. These operations are reported here as case studies. The selected operations were reproduced in physical at ErgoLab (FCA ergonomics laboratory) on the chassis of an automobile, to verify the postures predicted by the simulation. An overhead conveyor allowed the rotation of the chassis and the variation of the work height in order to simulate the geometrical features of the assembly line. The assembling operations were carried out by a male operator, 1730 mm in height, that is representative of the P50M manikin.

The first selected operation was the mounting of the braking system tubes into the wheel arch. The operation consists in positioning the tubes of the braking system from the control unit on the support and in fixing them by applying pressure with the hand. At the same workstation, the system is later secured by two screws.

Figure 1 depicts, both in virtual and in physical, the posture of the operator to reach the working area where the work task is performed. As it can be seen, the working posture is not critical for the trunk but may require the operator to work with the hands at shoulder height, also because of visual needs.

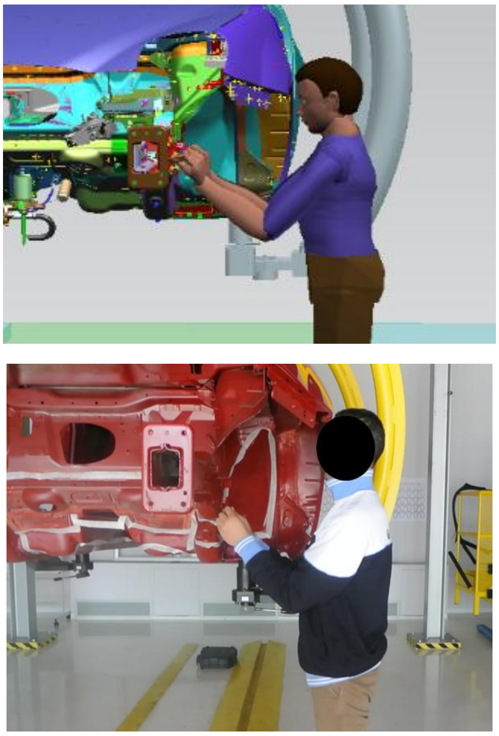


Figure 1: Virtual model and physical test of the tubes assembly case study

The second case study is relative to the antenna assembly on the car roof: the operator introduces the antenna cable connectors into the hole and manually fastens the antenna. The working posture is rather critical as the hatchback of the car limits the reachability of the car roof (Figure 2).

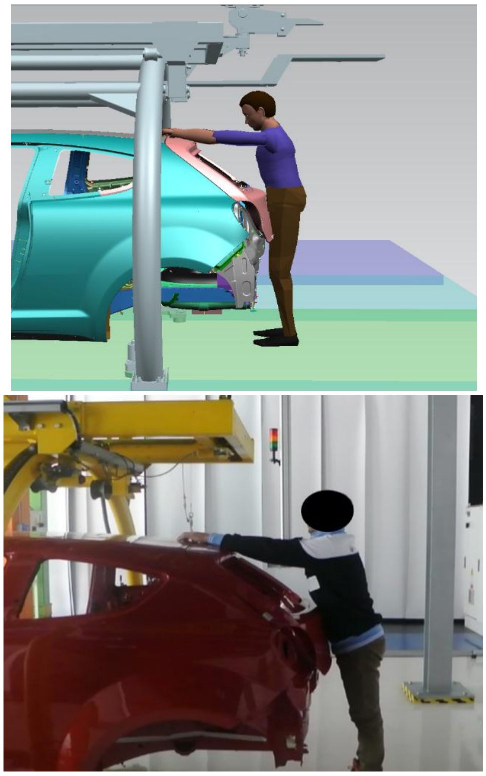
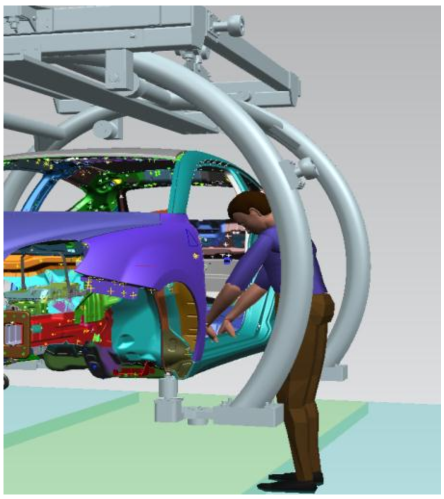


Figure 2: Virtual model and physical test of the antenna assembly case study

The third selected operation consisted in the application of the lower gasket in the door compartment: the operator inserts the gasket and extends it along the entire lower perimeter of the door. The task may require the operator to bend slightly the trunk, also to apply the pressure required for the gasket assembly (Figure 3).



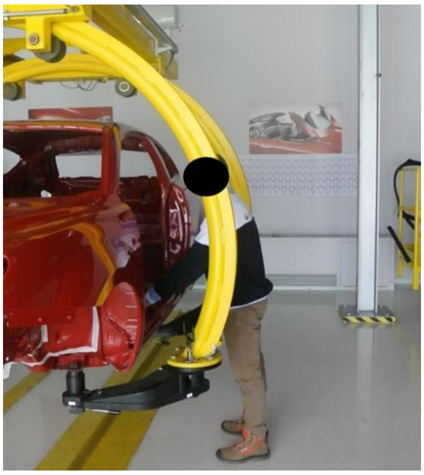


Figure 3: Virtual model and physical test of the gasket assembly case study.

A simple software tool for posture prediction and ergonomic assessment

The selected case studies were analyzed further. In particular, the Human Model (HM) software was used as a rapid screening tool to verify the postural angles for the limiting percentiles, in case the assembly line cannot be adjusted to the operator's anthropometry.

The HM program is a quick and simple tool that can run on a widespread program like Excel and can be used also by ergonomists that are inexperienced at virtual modeling. HM is used in FCA in the early design phase of the workstations on the production line, for its usability and speed in obtaining initial feedbacks. It is a simple multi-body model, where each body segment is modeled by a rigid segment of given length and zero mass and it is connected to the adjacent segments by means of joints. Each joint has a number of degrees of freedom that depends on the movements allowed for the joint. In particular, the pelvis and the shoulder are modeled as spherical joints, characterized by three degrees of freedom, whereas the elbow has one degree of freedom [19]. The kinematics of the anthropometric manikin has a hierarchical structure of nodes. The primary node is the pelvic joint, called root, whereas the others joints are derived nodes; this means that a rotation of the "father" joint causes the rotation of all "son" joints, on the contrary, a rotation of any "son" joint has no impact on the "father" joint. The inverse kinematics uses a reduced number of degrees of freedom: bending of the trunk, front elevation of the arm and elbow flexion. With this simplification, the manikin moves and simulates posture in a plane. The working point is identified with two coordinates (Z= vertical height from the ground and Y= horizontal distance from the body). The X coordinate of the working point (lateral distance) is automatically aligned to the elbow coordinate of the selected manikin.

When the point to reach with the hands is defined, the posture is predicted by solving an inverse kinematics problem. The posture prediction algorithm estimates the posture of the manikin according to two conditions:

1. If the working point is within the reachability area of the manikin arm, the manikin trunk is kept upright and the point is reached through rotation of the shoulder and elbow joints (γ and θ angle, respectively) (Kinematic condition 1).

2. If the working point is further away, the arm is kept extended and the point is reached through the rotation of the pelvic joint, i.e. causing trunk bending, and the rotation of the shoulder joint (α and γ angle, respectively) (Kinematic condition 2).

The manikin moves in the predicted posture in order to reach the defined working point. Then, the HM calculates the postural angles according to the technical standards [10-11]:

- The angle of trunk bending (α) is defined as the inclination of the trunk with respect to the vertical axis. In particular, the segment that defines the trunk bending is the line connecting two anthropometric points of the manikin, the greater trochanter to the 7th cervical vertebra. In Figure 4, angle α is drawn on the HM graphical interface.
- The upper arm elevation angle (γ) is defined as the elevation of the upper arm during task execution with respect to a reference posture. The segment that defines the elevation of the upper arm is the line connecting two anthropometric points of the manikin, the acromio-clavicular joint to the humeral-radial joint. The calculated angle does not depend on the direction of view during the measurement, but it is the real angle in 3D, while the angle of the reference posture of the arm is 13° from the vertical. In Figure 5, angle γ is drawn on the HM graphical interface.

The anthropometric model of the HM software refers to the international technical standards [20-21]. The user can select the anthropometry of the virtual manikin by setting the gender, the population of interest, and the percentile. The anthropometric percentile is a statistical concept that allows anthropometric measurements of an individual to be expressed in relation to the statistical population distribution [22]. In the design of a workplace, the ergonomics guidelines indicate that it must be verified both for the "average man" and for the limiting users that can be assigned to the workstation. This would require the P50M manikin, as well as the P5F (5th female percentile) and the P95M (95th male percentile) manikins, to be considered in the workplace assessment.

In this work, results of postural simulations for three case studies and the P50M, P5F and P95M virtual manikins were compared. The manikins were generated through reference anthropometric measurements in accordance with the technical standards [16, 17] for the population of interest. The Italian population was selected for this work:

- P50 M (1719 mm in height)
- P5 F (1490 mm in height)
- P95 M (1834 mm in height)

DISCUSSION OF CASE STUDIES

The HM allows the ergonomist to view the posture of the operator in the front, sagittal, and transverse plane as well as to calculate the value of the trunk bending and the upper arm elevation angles. Postural angles are colored according to a traffic light evaluation scheme, in agreement with the international technical standards ISO 11226 and EN 1005/4.

Table 1 summarizes the horizontal (Y) and vertical (Z) coordinates of the working point for the three case studies, as well as the calculated postural angles for the different manikins. The traffic light evaluation is also provided for the different angles.

Table 1: Postural angles and ergonomic traffic light evaluations

Working Point (mm)		Manikin	Trunk bending (α)	Upper arm elevation (γ)
1	Y=500; Z=1400	P50 M	0°	47°
		P5 F	0°	91°
		P95 M	0°	30°
2	Y=800; Z=1400	P50 M	14°	105°
		P5 F	42°	166°
		P95 M	9°	91°
3	Y=500; Z=800	P50 M	18°	47°
		P5 F	11°	57°
		P95 M	22°	45°

The traffic light evaluation corresponds to the ergonomic risk assessment of the posture:

- $0° \leq \alpha, \gamma < 20°$ acceptable condition (green)
- $\alpha, \gamma < 0°$, $20° \leq \alpha, \gamma < 60°$ condition to be verified (yellow)
- $\alpha, \gamma \geq 60°$ unacceptable condition (red)

For the first case study, the working area is represented by a horizontal distance of 500 mm and a vertical distance from the ground of 1400 mm. Figure 4 shows, in consecutive order, the simulated postures for the P50M, P5F, and P95M manikins. The graphic interface of the HM shows the sagittal view of the selected manikin.

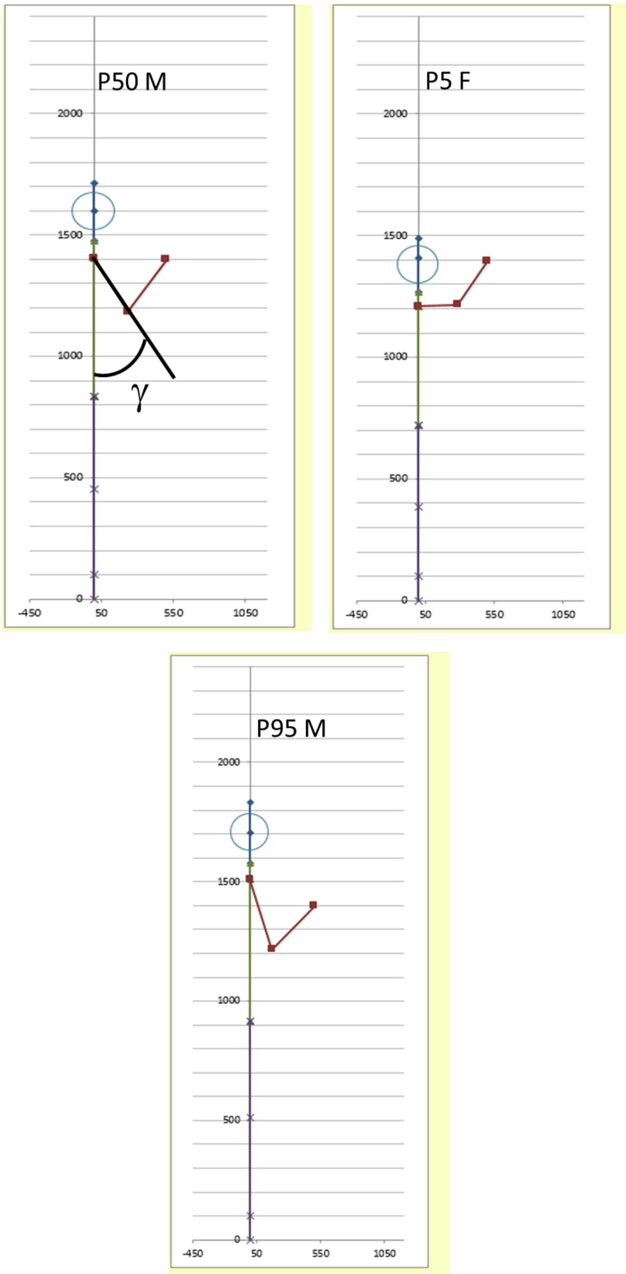


Figure 4: Predicted posture for the different manikins – case study 1

The comparison of the three anthropometries shows different predicted postures for the reachability of the working area. No manikin bents the trunk to reach the working area, but the posture of the arm is rather different for the three percentiles:

- P50M: $\alpha \simeq 0°$; $\gamma = 47°$
- P5F: $\alpha \simeq 0°$; $\gamma = 91°$
- P95M: $\alpha \simeq 0°$; $\gamma = 30°$

The upper arm elevation angle for the P5F manikin is obviously greater and leads to an unacceptable posture of the upper limb. For the male percentiles, the amount of arm elevation is yellow coded and needs to be considered also with respect to the time duration. Visual needs should be verified for the taller percentile, considering the increase in the visual distance.

For the second case study, the working area is represented by a horizontal distance of 800 mm and a vertical distance from the ground of 1400 mm.

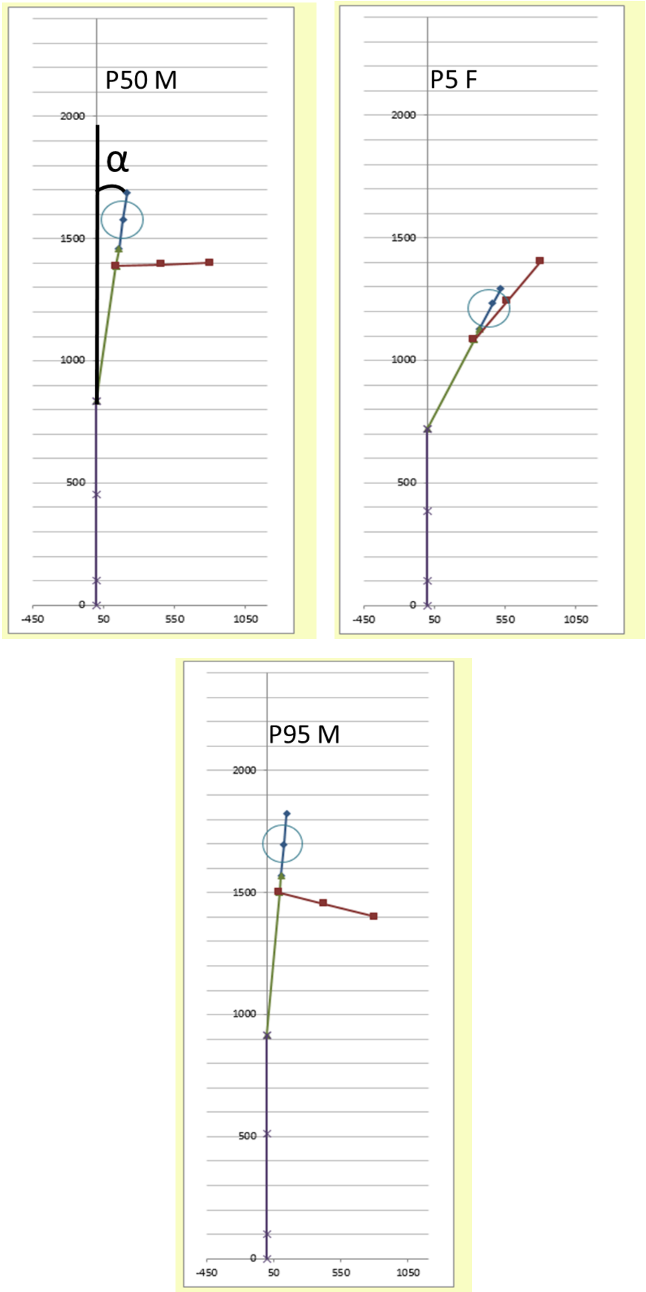


Figure 5: Predicted posture for the different manikins – case study 2

The working area is more distant from the body and, therefore, it is more difficult to reach (Figure 5). In particular, the reachability of the working area requires both the bending of the trunk and the upper arm elevation for all the three anthropometric percentiles:

- P50M: $\alpha = 14°$; $\gamma = 105°$
- P5F: $\alpha = 42°$; $\gamma = 166°$
- P95M: $\alpha = 9°$; $\gamma = 91°$

Although the upper arm elevation angle exceeds the recommendable limits for all percentiles (unacceptable condition - red light), in the case of the P5F manikin, also the trunk bending angle appears potentially critical (yellow light).

Finally, for the third case study, the working area is represented by a horizontal distance of 500 mm and a vertical distance from the ground of 800 mm.

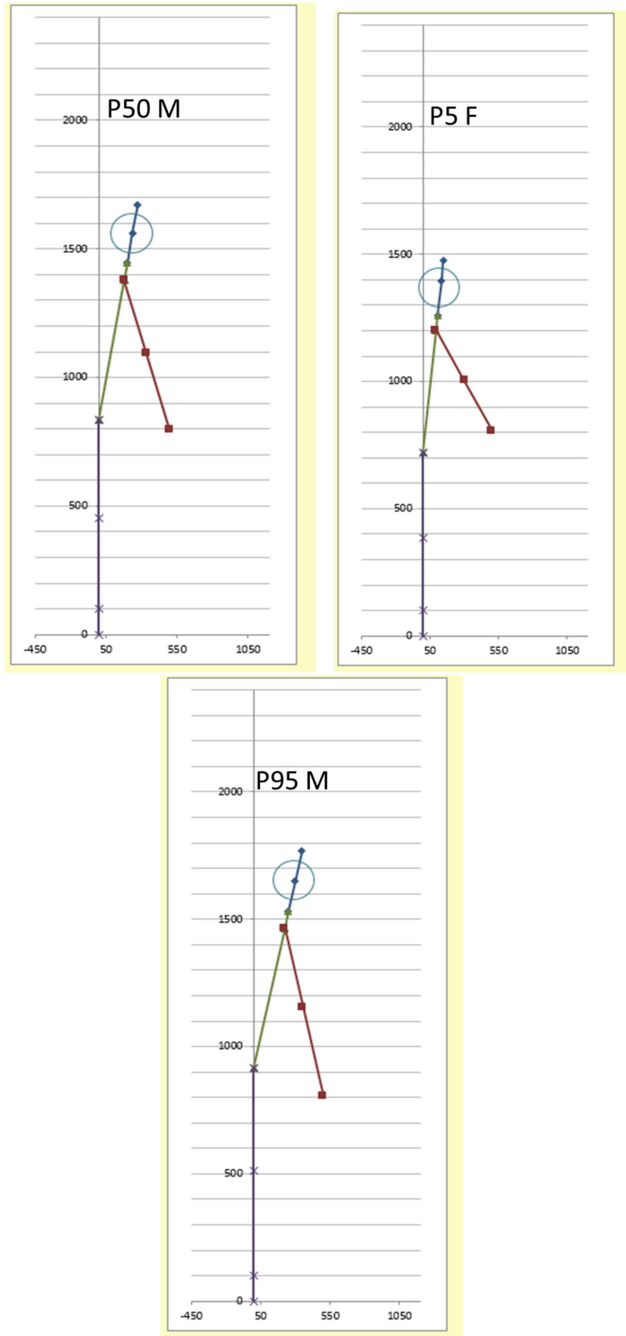


Figure 6: Predicted posture for the different manikins – case study 3

The working area has a lower vertical distance from the ground and may require a certain degree of trunk bending (Figure 6). In particular, the calculated postural angles are:

- P50M: $\alpha = 18°$; $\gamma = 47°$
- P5F: $\alpha = 11°$; $\gamma = 57°$
- P95M: $\alpha = 22°$; $\gamma = 45°$

Also in this third case study, the P5F manikin requires significant upper arm elevation and represents the limiting user. Indeed, for reachability problems, guidelines for the workstation design often indicate the verification of the P5F manikin. However, trunk bending is greater for the P95M manikin, since the working area is rather low and it is, therefore, easier to reach for a short operator.

These examples and the synthetized data of Table 1 highlight the benefit of a rapid screening tool to verify the postural comfort of the limiting percentiles, for whom the reachability and clearance problems are notoriously more critical.

CONCLUSIONS

The focus of the paper is on the anthropometric differences in the postural analysis of workstations and on the added value of simple simulation tools to verify the postural angles for the limiting percentiles, especially in case the assembly line cannot be adjusted to the operator's anthropometry.

Three case studies were selected from the digital modeling of FCA production lines and the designated assembly operations were reproduced in physical in the laboratory to verify predicted postures for the P50M manikin. A simple multibody model, developed by FCA in collaboration with the academia, was then used to verify the postural comfort of the defined workstations for the P5F and P95M manikins, for whom the reachability and clearance problems are notoriously more critical.

The simplicity and speed of the multibody model make it particularly useful for assisting the ergonomist in the early stages of the workstation design. In case the line already exists and cannot be varied in height, the postural assessment for manikins of different anthropometry may support the ergonomist to allocate the operators at the different workstations.

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