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Ergonomic application of virtual anthropometric mannequins in industrial environments

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ABSTRACT

This article proves non-ergonomic postures through virtual simulation and analysis of the work area. Blender software is used to correct non-ergonomic postures after modifying the welding area. The research was conducted finding bad postures in workers, including fatigue levels, through an ergonomic survey in combination with the use of the Likert scale. The Blender software results allowed us to find that the lack of early correction of these non-ergonomic postures can cause discomfort and pain, as well as injuries to the neck/nape, middle back, and lumbar back. Some recommendations were proposed to minimize discomfort and pain in the workers, for example, by reducing the angle of inclination for back and neck. The paper shows the utility of using software for digital anthropometry in an Industrial environment.

Keywords: ergonomics. digital anthropometry, occupational health, virtual anthropometric mannequins.

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Introduction

The use of anthropometry is needed when an ergonomic assessment is performed, which includes measuring the dimensions of the human body. The knowledge and techniques necessary to carry out the measurements, as well as their statistical treatment, are subject to anthropometry (Maradei, Espinel & Peña, 2008). The Ergonomics is complemented by Industrial Safety, which oversees the reduction of risks that exist in the industry, such as musculoskeletal injuries, circulatory or spinal problems, in addition to aches and pains in the neck, back, shoulders and legs, among others. The implementation of Ergonomics reflects positive changes in production systems (Márquez, 2012), which allows achieving Industrial safety, but it is also necessary to design ergonomic workspaces to reach the safety and health of workers (Mohammad & Mohamed 2007). This leads to the optimization of human action and avoids the appearance of ergonomic risks in workers, based on critical anthropometric measurements (Ávila, Prado & González, 2007; Rojas 2013).

We had the idea to develop anthropometric mannequins to visualize the impact in the different anthropometric percentiles applied to the work area. We considered using anthropometric evaluation software such as SolidWorks, which is a 3D CAD (Computer-Aided Design) software and offers the possibility to create, design, and simulate in 3D (Carrasco, 2006). We also considered using Make-Human, which is a free software graphics application for the creation of mannequins in three dimensions (Olabarria, 2014). In the end, we deemed it more appropriate to use the Blender software, since modeling, texturing, lighting, animation, and rendering of graphics can be done in three dimensions. Some studies has focused on improving the design of patterns of the virtual human body through software (Cichocka, Bruniaux & Frydrych, 2014), since the objective is always the same, the welfare of the workers and the satisfaction of the client, for this purpose Anthropometry plays a very important role in the industrial sector, design and ergonomics.

The critical factor for adequate absorption of the results is the participation and commitment of the sector (companies) in the development of tools and proper spaces in the work area.

The virtual mannequin concept has many applications, such as virtual commerce and design. Within the design approach, it must be guaranteed that virtual mannequins are anthropometrically correct (Ballester et al. 2015).

We developed a virtual environment that, with the help of Blender software, allows a wide range of options to modify the dimensions (anthropometric measures) of a virtual mannequin to detect bad ergonomic postures in the operators. This provided an opportunity to observe the benefits of changing some aspects in a simulated work environment to avoid situations that could cause different risks for the workers.

The purpose of this study is to detect bad postures using virtual environments. Parameterized anthropometric mannequins that include the different anthropometric percentiles were developed and visualized, enable us to offer benefits such as the reduction of discomfort and musculoskeletal injuries when changing aspects of the workplace. This will help reduce occupational risks in

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companies and highlight the fact that if work positions are improved, workers are less likely to be injured and tired, thus becoming more productive, which benefits the company.

Materials and Methods

Selection of study design

A metal-mechanical turnaround company was selected in the city of Mexicali. Within the company, four operators from the welding area were selected to answer an ergonomic survey by considering the main anthropometric measures for workers whose activities are developed in a standing position, which are shown in Figure 1.

The survey was designed to measure the level of fatigue and frequency in each of the anthropometric measurements of each worker in the area. The questions were focused on discomfort, inconvenience, and pain.

The following discomforts or conditions in employees are indications of an ergonomic risk: musculoskeletal injuries in shoulders, neck, hands and wrists; spinal problems, which can become severe and chronic; neck and back pains; discomfort or pain in the shoulders and legs. These conditions were measured using the Likert scale as shown in Table 1.

Definition of the condition to study

This research studied the level of fatigue caused by non-ergonomic positions adopted by each operator in the welding area. The welding area has two stations: Station 1, where the sides of the metal cabinets are placed and welded; and station 2, where a top tool is used to weld.

Table 1. Qualifications and identification by color in the ergonomic survey.

Likert scale	Colour
Nothing uncomfortable	Green
Little uncomfortable	Yellow
More uncomfortable	Orange
Extremely uncomfortable	Red

Source: (Matas, 2018).

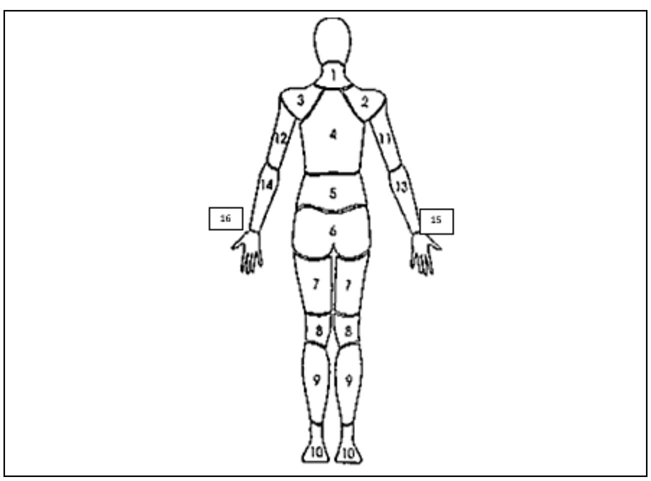


Figure 1. Anthropometric measures for standing position. 1) Neck/nape, 2) Right shoulder, 3) Left shoulder, 4) High-middle back, 5) Lumbar back, 6) Hip, 7) Thighs, 9) Legs, 10) Feet, 11) Right arm, 12) Left arm, 13) Right forearm, 14) Left forearm, 15) Right wrist, 16) Left wrist.
Source: (Ergonomía, Programa teórico y C. de Prácticas. [Online]).

The problem of fatigue occurs in station 1 as it does not have adequate furniture for the placement and welding of laterals, which leads workers to adopt non-ergonomic postures.

The level of fatigue presented by each operator varies depending on their height (percentile). Shorter operators do not need to lean too much to place laterals on top of the platform, as shown by the Blender software in Figure 2.

Figure 2. Critical posture 1 (percentile 5, 1.69 m) bend to place and weld metal sides.
Source: None.

The tallest worker has greater lumbar inclination when bending for lateral placement, as shown in Figure 3.

Figure 3. Critical posture 2 (percentile 95, 1.85 m) bend to place and weld metal sides.
Source: None.

A table of critical angle ranges was developed to determine the essential measurements of the lumbar back. Table 2 shows the proposed angle categories of the lumbar back, which was made based on recommendations from many authors [12], [13].

Table 2. Qualifications and identification by color in the ergonomic survey.

Categories (Lumbar Back)	
Neutral	0°
Mild	(-20 to 20°)
Moderate	20 to 30°
Mean	30 to 45°
Severe	45 to 60°
Very severe	60 to 80°
Serious	80 to 90°
Profoundly serious	>90°

Source: None.

A digital projection of the pelvis and spine bones was created to calculate the angle of inclination of the lumbar back using the following equation:

$$\theta = arccos[(AB)/(|A||B|)] \quad (1)$$

Where AB is the scalar product of the vectors and |A||B| is the modules of each vector.

Results and Discussion

This research demonstrates the results obtained by taking anthropometric measures with critical measures (Figure 4), developing the mannequin using the Blender software, and applying an ergonomic survey (Figure 5) to workers in the metal-mechanics industry, specifically in the welding area, is a company located in the city of Mexicali. The study helped us identify the level of fatigue in workers using the Likert scale as a measuring instrument.

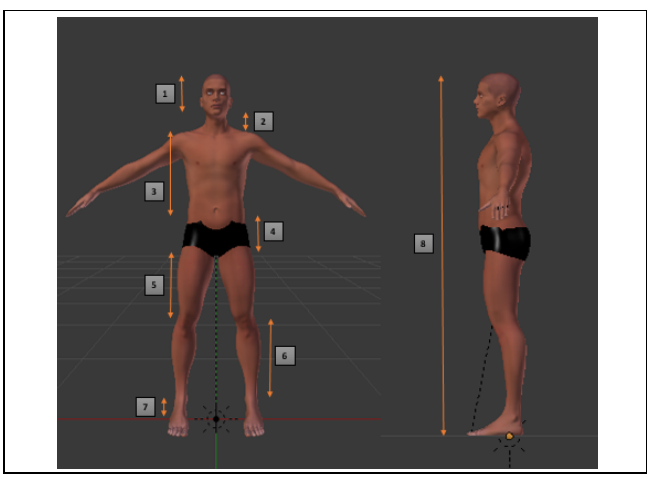
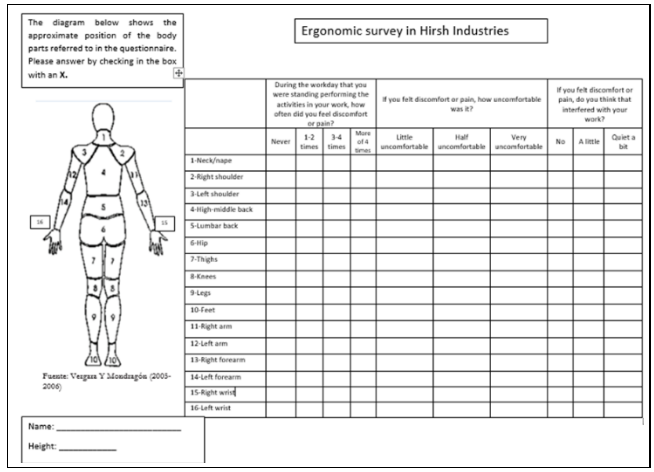


Figure 4. Critical measures using Blender.
1) Head-height, 2) Neck-height, 3) Torso-height, 4) Buttock-height, 5) Upper leg-length, 6) Lower leg-length, 7) Feet-height, 8) Height.
Source: None.



The diagram below shows the approximate position of the body parts referred to in the questionnaire. Please answer by checking in the box with an **X.**

Ergonomic survey in Hirsh Industries

	During the workday that you were standing performing the activities in your work, how often did you feel discomfort or pain?				If you felt discomfort or pain, how uncomfortable was it?			If you felt discomfort or pain, do you think that interfered with your work?		
	Never	1-2 times	3-4 times	More of 4 times	Little uncomfortable	Half uncomfortable	Very uncomfortable	No	A little	Quiet a bit
1-Neck/nape										
2-Right shoulder										
3-Left shoulder										
4-High-middle back										
5-Lumbar back										
6-Hip										
7-Thighs										
8-Knees										
9-Legs										
10-Feet										
11-Right arm										
12-Left arm										
13-Right forearm										
14-Left forearm										
15-Right wrist										
16-Left wrist										

Fuente: Vergara Y Mondragón (2005-2006)

Name: ____________________

Height: __________

Figure 5. Fatigue level survey.
Source: None.

The Table 3 shows the Likert scale and order of the score obtained using the ergonomic survey.

Table 3. Order of the score obtained.

Order of the score obtained in the survey	Assigned value (Likert scale)
01 to 12	1
13 to 24	2
25 to 36	3
37 to 48	4

Source: None.

Table 4 was obtained from the responses of the ergonomic survey, using the Likert scale to have a counting value. The values of the reactions of each worker were added, and four ranges were calculated to determine the level of fatigue and pain of workers with inadequate postures.

Percentiles (height) of the workers, as well as an image of the working environment, were uploaded in the Blender software to obtain the positions workers adopt in the workday and to calculate lumbar back angles. Figure 6 shows the inclination comparison between both percentiles.

Table 4. Results obtained after survey application.

Body dimensions	Worker 1 (1.69m P>50)	Worker 2 (1.70m P>50)	Worker 3 (1.76m P>50)	Worker 4 (1.85m P>50)	Sum	Likert scale
Neck/nape	18	2	8	6	34	3
Right shoulder	2	2	4	2	10	1
Left shoulder	2	6	12	2	22	2
Back	12	6	6	4	28	3
Lumbar Back	12	4	4	4	24	2
Hip	2	2	8	2	14	2
Thighs	2	9	2	2	15	2
Knees	8	2	4	2	16	2
Legs	2	4	8	2	16	2
Feet	2	6	2	2	12	1
Right arm	2	2	2	2	8	1
Left arm	2	8	2	2	14	2

Right forearm	2	2	2	2	8	I
Left forearm	2	2	2	2	8	I
Right wrist	2	2	3	2	9	I
Left wrist	2	2	2	2	8	I

Source: None.

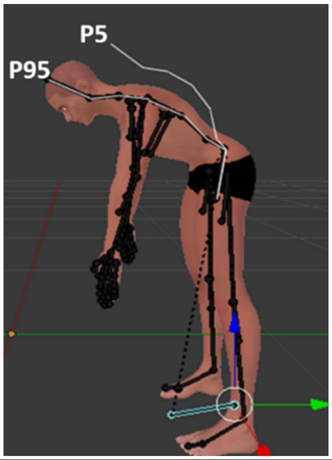


Figure 6. Inclination comparison between both percentiles (P5 and P95).
Source: None.

The angle of inclination is the result of the activity that workers must perform, which is leaning on a platform to place sides and weld them. This action is very repetitive since they perform around 10 welding points in each cabinet and do approximately 45 to 50 cabinets a day.

We can see that the fatigue level could be related to anthropometric measurements. Thus, the tallest workers could be more propense to injuries related to spinal inclination, since workers in the 5th percentile lean at an angle of 57°, and the workers in the 95th percentile lean at an angle of 66°.

The results show that the data obtained when applying the ergonomic survey coincide with the level of risk. The result of the ergonomic survey was level 3 (red) causes pain (musculoskeletal injuries), and the Blender software resulted in serious for the 5th percentile and very serious for the 95th percentile. Both methods gave us very similar results, which shows that it is necessary and urgent to make a change in the work tool used in the welding area of the company. Our recommendation suggest to adjust each worker's workspace to their height, placing it at the level of the elbows or slightly below in order to reduce the angle of inclination in the lumbar back and obtain a more suitable angle range. An adjustable table could be used to suit different heights.

Figure 7 shows a comparison in the reduction of inclination in the lumbar back of both percentiles. The worktable is raised 25 cm to reduce the angle of inclination of the lumbar back in both percentiles. The lumbar back angle reduces (P5) of 57° to 23.2° (59.3%). The lumbar back angle reduces (P95) of 66° to 37.4° (43.4%).

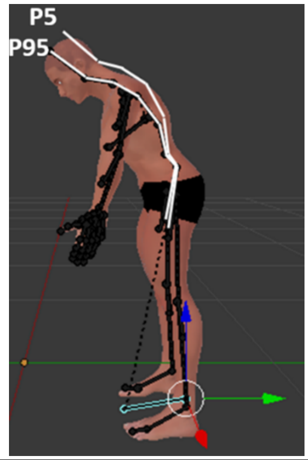


Figure 7. Inclination comparison between both percentiles (P5 and P95) with improvement.
Source: None.

Conclusion

The use of virtual environments (anthropometric mannequins) allowed the prediction of ergonomic risks, such as musculoskeletal injuries in workers within the industrial sector, as well as the reduction flexion angles in the lumbar back for P5 and P95 of 59.3% and 43.4%, respectively, at workstations.

The data obtained indicated that the workers presented higher ergonomic risk in the following anthropometric dimensions: neck/nape, back and lumbar back with scores 3, 3, 2, respectively, on the Likert scale. However, although the neck/nape and back dimensions have a more excellent value in the Likert range, the angles were not calculated because it would imply having detailed knowledge of the measurements of each of the bones (L. Abad Toribio et. al., 2013). This information is taken as the basis for calculation using the Blender software.

An improvement to reduce the angle of flexion of the lumbar back, consisting of the modification of the height of worktables within the work area, was recommended to prevent ergonomic risk.

The scope of this paper is generally limited to the calculation of inclination angles in the lumbar back and the implementation and improvement of the workspace, reserving further discussion to the calculation of flexion angles in neck and back as well as their respective improvements for an ergonomic design for future research.

This work intends to put the situation into perspective by showing the differences between percentile variations of the anthropometric dimensions. Lack of consideration of the anthropometric measurements of workers could result in uncomfortable and non-ergonomic workspaces.

Using Blender software to analyze postures and positions in the workspace could help us evaluate the inclination angles of the back, neck, and arms to determine inadequate (non-ergonomic) positions and correct them.

The digital analysis of work postures can be an early detection tool for musculoskeletal risks, meaning it is proactive, while the ergonomic survey is reactive because it shows the existing risks of the workers. The method of digital analysis of work postures may be the best option in this study.

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