Research Article

# Ergonomic analysis of a working posture in steel industry in Egypt using digital human modeling

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**Abstract**
This study presents solutions for improving a bending awkward posture in steel industry in Egypt using digital Human Modeling (DHM). The information is gathered by interviewing the workers, working postures are recorded via a video camera while the worker is performing his usual work. The postures are analyzed using DHM software. Porter comfort analysis and Rapid Upper Limb Assessment are applied for postures analysis. The analysis shows high levels of discomfort in neck, trunk, leg and forearm. These discomforts could cause permanent injuries over long periods. A modified design is proposed to reduce the fatigue caused by the original process. Furthermore, a comparison between the old and new design is performed. This study is important as workers comfort and productivity are increased when the work environment is ergonomically well-designed.

**Keywords** Ergonomics analysis · Musculoskeletal disorders · Steel industry · Digital human modeling · RULA

## 1 Introduction

Ergonomics is the discipline of science concerned with understanding and analyzing the interactions between humans and their surrounding environment with taking the effect on the human abilities [1]. Improving the ergonomics in workplaces increases the overall productivity of workers and consequently the factory. Despite this fact, some industrially developing countries still neglect design for ergonomics although they strive to increase their productivity. This is in many industrial sectors such as the semiconductors sector. It is widely thought that ergonomics cost is a burden and not as an investment [6]. However, well designed ergonomics is essential to manufacturing excellence [7].

Efficient ergonomic design is a process of high complexity and requires high investment of money and time. It also requires a highly skilled team with interdisciplinary engineering and scientific background. However, Lack of ergonomics analysis can lead to various injuries and risks such as joints sprains, muscle strains, and musculoskeletal disorders (MSDs) that are caused by awkward postures, carrying heavy loads, and repetitive movement [2]. In any industry such as steel industry, the main contributor to health problems are the occupational risk factors. For instance, exposure to high levels of noises or extreme heat for long periods can lead to occupational illnesses. The industrial environment in a factory with its noise, exhaust the workers [3]. Workers in power and steel industries are exposed to many hazardous activities that lead to higher probability for serious accidents causing death or diseases [5].

In this manner, the International Labor Organization (ILO) [4] estimated that the number of deaths due to diseases and accidents that occur to people from both genders in work environment exceeds the 2.3 million per

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year worldwide. This is corresponding to more than 6000 deaths on daily basis. Furthermore, work-related illness causes the death of over 160 million workers annually. Again, the number of occupational accidents exceeds the 340 million accident annually. The data is regularly updated by the ILO and the updates show that the accidents numbers are rising each year.

Digital human modeling (DHM) is an efficient technique for ergonomics design, analysis and prediction. It gets more efficient when integrated with computer-aided engineering (CAE) software [8]. For example, Dassault Systems Company integrated SAFEWORK which was a standalone product with CAE as a digital human modeling software [15]. Now, SAFEWORK is integrated with both CATIA V5 [9] and (DELMIA V5) software [10] which are used for product design and manufacturing planning respectively as a workbench for computer added design (CAD). The integration allows the existence of the product model and the human model in the same environment. This makes the design and simulation of different human postures or tasks easier, realistic, more accurate, and less time-consuming process [11]. Rapid Upper Limp Assessment (RULA) is integrated with CATIA V5 software DHM module and is based on the work of McAtamne et al. [12]. This type of comfort assessment is concerned with the upper part of human body. Furthermore, Siemens NX software named has a DHM module named NX Human Modeling and Posture Prediction previously named JACK [13, 14, 16] based on the work of Porter et al. in [17].

There are many DHM software developed for various purposes and design needs as the 3DSSPP software for materials handling [18]. Moreover, SANTOS was developed serving different industries including aerospace, military, and medical ergonomics [21]. Another DHM software specialized for car crash simulations and safety MADYMO software [19]. Again, RAMSIS software is developed for vehicle ergonomics simulation and analysis [20–22].

This paper provides a convenient assessment of the work station in the steel industry. In Sect. 2, the detailed methodology followed in the article is illustrated. First, questionnaires were performed. Furthermore, worker's postures were recorded by a video camera and main positions of the worker were determined. Moreover, Upper Limb Assessment (RULA) and Porter comfort assessment were executed using CATIA V5 and Siemens NX software. Furthermore, Sect. 3 contains the initial results and discussion. Upon software results, some improvements are suggested and approved via simulation in Sect. 4. Section 5 contains a comparison between the initial and final results. Relevance of previous work is discussed in Sect. 6. Finally, the work is concluded in Sect. 7.

## 2 Methodology

This section contains the detailed research strategy, methods and interview questions during the data collection phase.

### 2.1 Research strategy

First previous related studies are investigated. Furthermore, initial screening take place through interviews. Then, the problem main theme is defined, and suitable methods are selected. Afterwards, analysis is performed through DHM Software. Moreover, improvements are suggested upon the analysis. Finally, the improvements are verified through further DHM analysis.

### 2.2 Previous related studies and methods

Some previous studies on ergonomics analysis in steel industry were investigated and listed in Table 1.

More methods and their corresponding risk factors are presented in [29].

**Table 1** Previous studies and corresponding methods

| Research title | Methods used |
|---|---|
| Ergonomics Intervention in Unit Blast Furnace of a Typical Steel Company [24] | Nordic Musculoskeletal Questionnaire (NMQ)—Rapid Entire Body Assessment (REBA) |
| Ergonomic assessment and workstation design of shipping crane cabin in steel industry [25] | Questionnaire—RULA |
| Ergonomics Analysis in the Scarfing Process by OWAS, NIOSH and Nordic Body Map's Method at Slab Steel Plant's Division [26] | Nordic Body Map questionnaire—Ovako Work Posture Analysis System (OWAS) |
| Assessment of Risk of Musculoskeletal Disorders among Crane Operators in a Steel Plant: A Data Mining–Based Analysis [27] | NMQ |
| Ergonomic Study and Design of the Pulpit of a Wire Rod Mill at an Integrated Steel Plant [28] | RULA–REBA–OWAS–Quick Exposure Check (QEC) |

### 2.3 Working conditions and initial screening

In the initial screening phase, 16 workers were interviewed at the factory and asked if they are feeling any pain due to their work duties. This is to get initial view on which subject should be analyzed and get an overview of the problem taking into consideration that the company does not have its own comfort assessment. The worker was chosen because his work is repetitive, and he had the most awkward postures among his colleagues. The working cycle postures were recorded using a video camera while performing his usual work. Postures which are seen to be significant were chosen for the study as shown in Fig. 1.

The job process is that the worker first places a bulk cylinder of mild steel that weighs more than 50 kg to the strip saw machine mechanical vise. Then he tightens up the bench vise to the part and starts cutting the pillar to the required length. Furthermore, the pillar is taken to the lathe to be formed according the set design.

### 2.4 Study main theme

This study is performed at a steel factory in Egypt. It is obvious that the worker's duties are mostly depending on the upper part of his body and partially on his legs. Thus, RULA is found to be an appropriate method for ergonomics analysis under the illustrated condition. Porter comfort assessment is concerned with the whole body and it is considered as a confirmatory assessment in this study.

### 2.5 RULA and Porter analysis

After the initial screening, the chosen postures were modeled using Digital Human Modeling Software. The RULA was performed through CATIA V5 software while Porter full body assessment was performed on Siemens NX11 software. Regarding human modeling on CATIA V5 and Siemens NX, there is a module that enables inserting a Manikin representing a human model. The Manikin is initially in a standing position. All body parts of the model can be modified to represent any real posture. After simulating the real posture, the assessment is performed as an integrated feature. The three postures are modeled on both software following the previously stated measures.

The Human Model in CATIA V5 does not show which body parts are less comfortable as shown in Fig. 2. On the other hand, Siemens NX shows the body part that has high levels of discomfort as shown in Fig. 3.

Figure 3 shows the three modeled postures for the worker placing the bulk cylinder to the strip saw machine mechanical vise. The right arm and shoulder are showing high levels of discomfort due to the stress while positioning the part and tightening the vise. Both legs are also showing high levels of discomfort for the same reason.

## 3 Results and discussion

### 3.1 Interview result

Interviewing the subjects is an inefficient way to detect if the postures are awkward or not. However, it was performed to get a broad overview on body parts under high risk. Based on the interview, the worker had experienced irritation in the rest, trunk, forearm, leg, lower back, knee, thighs, hips, elbow, waist, and foot while conducting his job tasks. The worker is asked about each body segment to provide a discomfort level (Low, Medium, High). Furthermore, it is obvious that the raw material bulk weight is very high and require high effort to handle, specially that task is repetitive. The interview results are shown in Table 2.

### 3.2 RULA results

Using CATIA V5 software RULA analysis was performed for each posture and the results for the three postures

**Fig. 1** Awkward recoded working postures

**Fig. 2** Corresponding human model postures using Catia V5

**Fig. 3** Corresponding human model postures using Siemens NX11

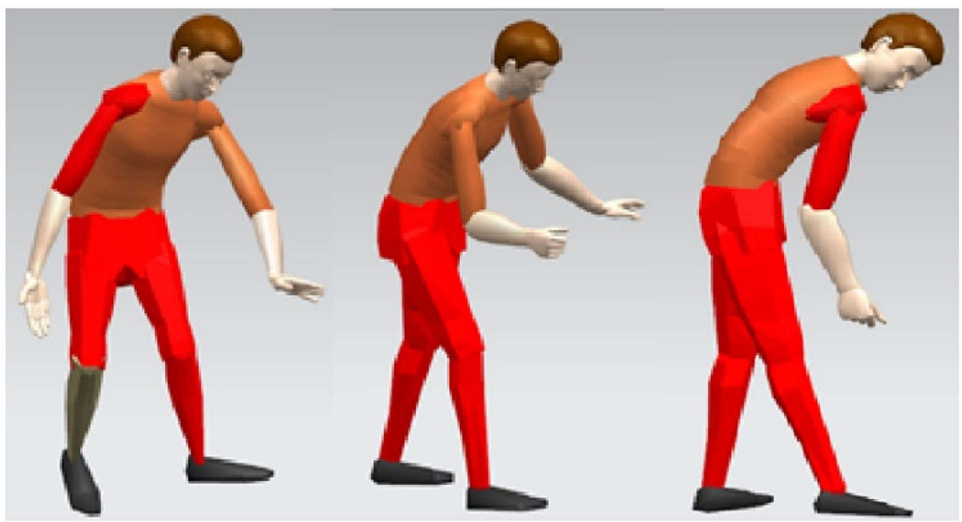

**Table 2** Interview results for each posture

| Segments | Comfort levels for each posture | | |
|---|---|---|---|
| | 1st posture | 2nd posture | 3rd posture |
| Rest | H | L | L |
| Trunk | M | H | H |
| Forearm | H | M | M |
| Leg | M | M | M |
| Lower back | M | H | H |
| Knee | H | L | M |
| Thighs | H | M | H |
| Hips | L | M | M |
| Elbow | L | M | M |
| Waist | M | M | H |
| Foot | M | H | L |

are summarized in Table 3. The analysis indicated that the postures are awkward, and the worker is at high risk with an overall score of 6 for the first and second posture and 7 for the third posture. Figure 4 shows RULA analysis for the second posture. Immediate Investigation and changes

**Table 3** Initial RULA score

| Posture | Score | Risk level | Action to be taken |
|---|---|---|---|
| 1 | 6 | Medium | Investigate further and change soon |
| 2 | 6 | | |
| 3 | 7 | High | Investigate and change immediately |

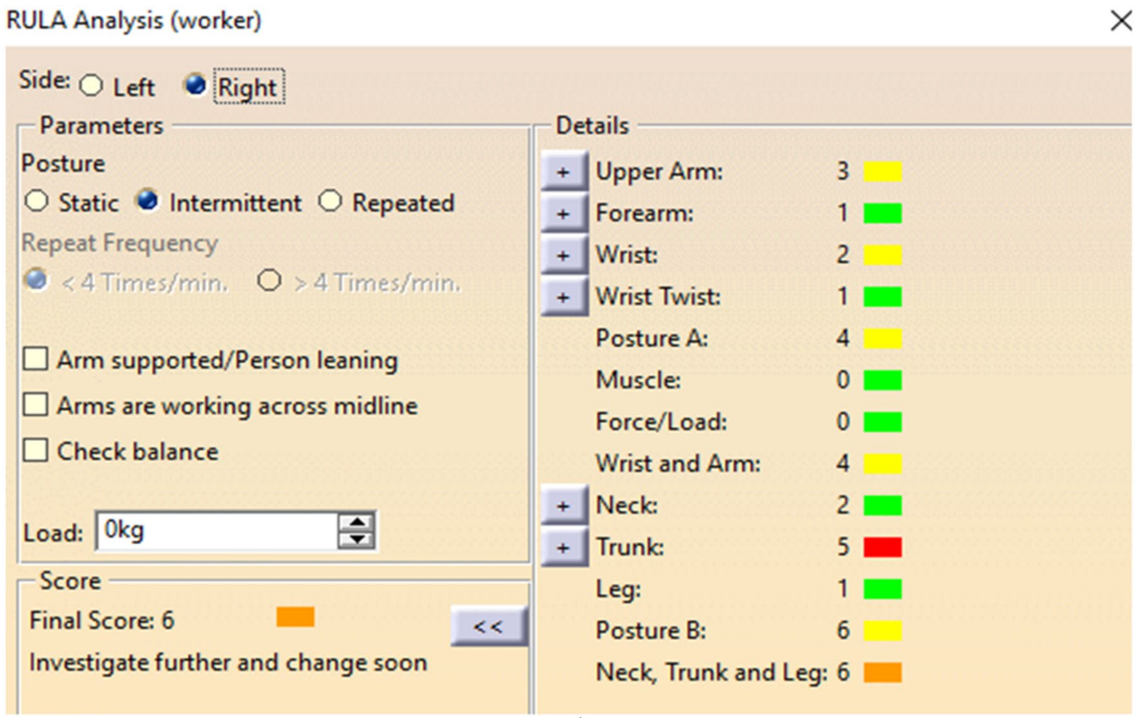


**Fig. 4** RULA for the 2nd posture using CATIA V5

are needed for the obtained results [30]. The highest risk is found to be within the forearm, Neck, Trunk and Legs.

### 3.3 Porter results

Siemens NX11 software was used for such assessment as shown in Fig. 5. The software's results are more of dynamic graphic bars representing the acceptable range for each body part that displaying the ratings on the model by using various colors (Red–Green) to represent comfort results for all body parts [23]. The results in Fig. 4 shows high level of risk at many body parts for the three postures, but the thigh and feet are the main problem.

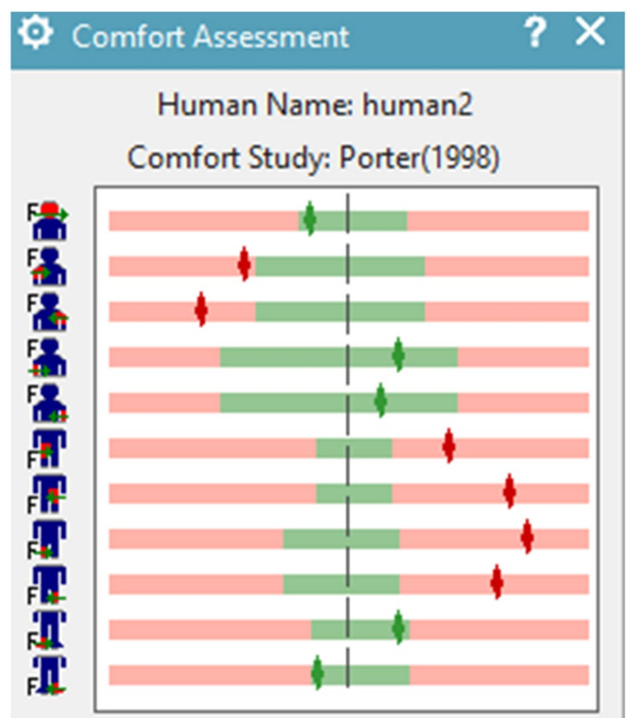


**Fig. 5** Porter assessment for the 3rd posture

## 4 Suggested modifications

To reduce the effort of pushing the bulk to the vise, a simple slider for the cylinder could be used as shown in Fig. 6a. A hinge vise as the one shown in Fig. 6b should be used instead of the bench vise. The workflow will change to be as follows:

1. The working part is placed on the slider.
2. The worker while standing slide the part to the vise.
3. Tighten the hinge vise while in standing posture.

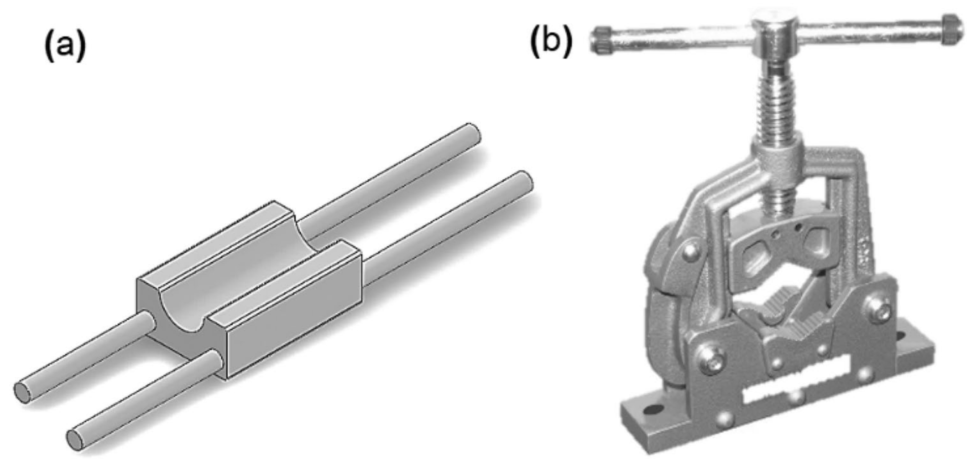


**Fig. 6** (**a**) Slider. (**b**) Cylindrical hinge vise

**Table 4** RULA score after improvements in workstation

| Posture | Score | Risk level | Action to be taken |
|---|---|---|---|
| 1 | 2 | Negligible | Acceptable if not repeated over long periods |
| 2 | 2 | | |
| 3 | 3 | Low | Investigate further |

This will make the worker standing in a straight position and eliminate the need for bending. The energy to do the job should reduce stress the minimum, MSDs are to be avoided, and productivity is increased.

## 5 Final analysis and results

Upon the improvements, the postures were modified and simulated using CATIA V5 and Siemens NX. RULA was repeated and the numerical output dropped from 6 to 2 for the first and second postures showing acceptable comfort levels. Furthermore, RULA numerical output dropped from 7 to 3 for the third posture which is better than the original status. The results summarized in Table 4 show the good impact of the improvements.

Furthermore, Porter assessment is performed and the graphical illustration in Fig. 7 shows that all body parts are within the green safe limits for the first and second postures. On the other hand, Porter analysis for the third posture after modifications showed 3 discomfort body parts conforming with RULA analysis.

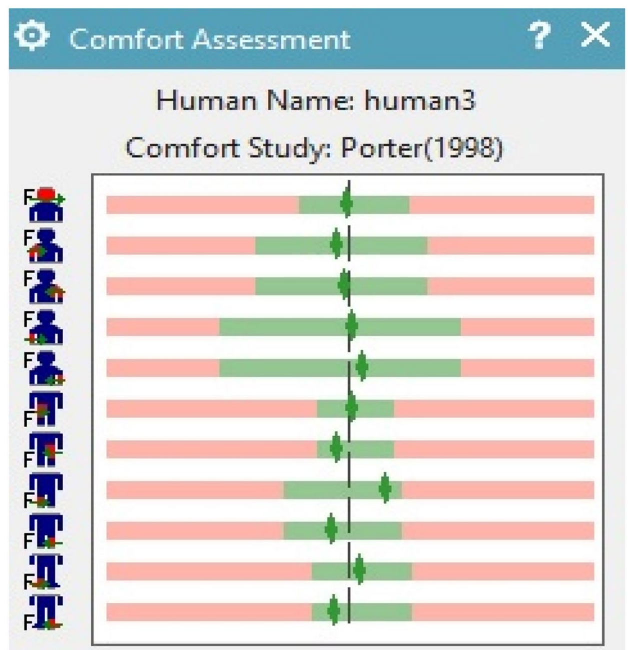


**Fig. 7** Final Porter comfort assessment using Siemens NX11

## 6 Discussion

Steel industry has many occupational risk factors and requires much attention regarding ergonomics design. The present study analyzed an awkward posture from the steel industry in Egypt using DHM. The authors succeeded in improving the current condition by suggesting new workstation or process design. The efficiency of the new modification got verified by performing RULA and Porter analysis. The findings of this study proved that industrially awkward postures can be efficiently analyzed and improved using DHM. For instance, interview results show high levels of discomfort in trunk, forearm, and lower back. When the postures got simulated and analyzed via DHM software, the results were conforming with the reality. In this context, previous studies analyzing postures of manual workers in small scale industries [30, 31] followed the same procedures and revealed that the RULA method is the best technique for predicting the risk of the occurrence of upper limb musculoskeletal disorders among the different examined tasks. Many previous studies used DHM to analyze and Kushwaha and Prasad Kane [25] used questionnaire and RULA for ergonomic assessment and modifying of crane cabin. Kushwaha and Kane had the privilege of collecting the data form 27 crane operators. In our case there was a limitation that only one person is performing the job. The analysis would be much more powerful if there were many workers performing the same job. Thus, future development of this research could be a deeper investigation and statistical analysis of ergonomics design in the Egyptian steel industry in general.

## 7 Conclusion

The study analyzed some awkward postures in a steel manufacturing company in Egypt. The results of the analysis matched the data collected. Based on the analysis, the suggested improvements achieve the highest ergonomic scores and ensure the workers' safety. These procedures meet the international standard for a proper workplace. Thus, it should be implemented to reduce the musculoskeletal disorders and decrease nonvalue added activities during operation. Further analysis was performed to verify the efficacy of the suggested modification. The modification analysis showed significant advancements over the original design.

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### Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflict of interest.

**Ethical approval** All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2000.

**Informed consent** Informed consent was obtained from all individual participants included in the study.

## References

1. Rozlina MS, Awaluddin SM, Abdul Hamid S, Norhayati Z (2012) Perceptions of ergonomics importance at workplace and safety culture amongst safety and health (SH) practitioners in Malaysia. In: Proceedings of the world congress on engineering, vol 1
2. Kulkarni VS, Devalkar RV (2018) Postural analysis of building construction workers using ergonomics. Int J Constr Manag 19(6):464–471
3. Halim I, Omar AR, Saad NH (2005) Ergonomic assessment for assessing work-related musculoskeletal disorders in Malaysian Metal Stamping Industry. In: Conference: 8th SEAES conference and 12th IPS congress, May 2005
4. International Labour Organization **(online)** http://www.ilo.org/. Accessed 21 Feb 2020
5. Sriyogi K (2014) An ergonomic evaluation of work place in steel and power industry—a case study. SSRN Electron J. https://doi.org/10.2139/ssrn.2431575
6. Wong SB, Richardson S (2010) Assessment of working conditions in two different semiconductor manufacturing lines: effective ergonomics interventions. Hum Fact Ergon Manuf Serv Ind 20(5):391–407
7. McGowan B (2019) Ergonomics: essential to manufacturing excellence. Prof Saf 7:43–45
8. Demirel HO, Duffy VG (2007) Applications of digital human modeling in industry. In: Digital human modeling lecture notes in computer science, pp 824–83
9. Li FX (2014) The application research on ergonomics based on the CATIA Software Platform. Appl Mech Mater 651–653:2050–2054
10. Polášek P, Bureš M, Šimon M (2015) Comparison of digital tools for ergonomics in practice. Procedia Eng 100:1277–1285
11. Fritzsche L (2010) Ergonomics risk assessment with digital human models in car assembly: simulation versus real life. Hum Fact Ergon Manuf Serv Ind 20(4):287–299
12. Mcatamney L, Corlett EN (1993) RULA: a survey method for the investigation of work-related upper limb disorders. Appl Ergon 24(2):91–99
13. Fritzsche L, Jendrusch R, Leidholdt W, Bauer S, Jäckel T, Pirger A (2011) Introducing ema (Editor for Manual Work Activities)—a new tool for enhancing accuracy and efficiency of human simulations in digital production planning, Digital human modeling lecture notes in computer science, pp 272–281
14. Raschke U, Cort C (2019) Siemens Jack. In: DHM and posturography, pp 35–48
15. Kim SH, Lee K (2009) Development of discomfort evaluation method for car ingress motion. Int J Autom Technol 10(5):619–627
16. Phillips CB, Badler NI (1988) JACK: a toolkit for manipulating articulated figures. In: Proceedings of the 1st annual ACM SIGGRAPH symposium on User Interface Software—UIST 88
17. Porter JM, Gyi DE (1998) Exploring the optimum posture for driver comfort. Int J Veh Design 19(3):255–266
18. Chaffin DB (1997) Development of computerized human static strength simulation model for job design. Hum Fact Ergon Manuf 7(4):305–322
19. Steffan H, Geigl BC, Moser A (1999) A new approach to occupant simulation through the coupling of PC-Crash and MADYMO, SAE technical paper series, Jan 1999
20. Bubb H (2002) Computer aided tools of ergonomics and system design. Hum Fact Ergon Manuf 12(3):249–265
21. Malek KA, Yang J, Marler T, Beck S, Mathai A, Zhou X, Patrick A, Arora J (2006) Towards a new generation of virtual humans. Int J Hum Fact Model Simul 1(1):2

22. Bubb H, Engstler F, Fritzsche F, Mergl C, Sabbah O, Schaefer P, Zacher I (2006) The development of RAMSIS in past and future as an example for the cooperation between industry and university. Int J Hum Fact Model Simul 1(1):140
23. Siemens Product Lifecycle Management Software Inc, NX Human Modeling and Posture Prediction, Prolim 2017
24. Motamedzade M, Shafii Motlagh M, Darvishi E (2020) Ergonomics Intervention in Unit Blast Furnace of a Typical Steel Company, wwwSIDir, 01-Jan-2013 **(online)** https://www.sid.ir/en/Journal/ViewPaper.aspx?ID=355103. Accessed 07 Mar 2020
25. Kushwaha DK, Kane PV (2016) Ergonomic assessment and workstation design of shipping crane cabin in steel industry. Int J Ind Ergon 52:29–39
26. Setyanto NW, Efranto RY, Lukodono RP, Dirawidya A (2020) Ergonomics analysis in the scarfing process by OWAS, NIOSH and Nordic Body Map's Method at Slab Steel Plant's Division, Semantic Scholar, 01-Jan-1970 **(online)**. https://www.semanticscholar.org/paper/Ergonomics-Analysis-in-the-Scarfing-Process-by-and-Setyanto-Efranto/abc5f6ff26eab845600819864d035f16179c5120. Accessed 05 Feb 2020
27. Krishna OB, Maiti J, Ray PK, Mandal S (2014) Assessment of risk of musculoskeletal disorders among crane operators in a steel plant: a data mining-based analysis. Hum Fact Ergon Manuf Serv Ind 25(5):559–572
28. Dewangan CP, Singh AK (2015) Ergonomic study and design of the pulpit of a Wire Rod Mill at an integrated steel plant. J Ind Eng 2015:1–11
29. Muñoz VZ, Petz M, Silveria Agullo Thomas M (2019) Ergonomic risk factors analysis with multi-methodological approach: assessing workers' activities in buildings under construction, Dyna, 01-May-2019 **(online)**. http://www.revistadyna.com/search/ergonomic-risk-factors-analysis-with-multi-methodological-approach-assessing-workers-activities-in-b. Accessed 02 Feb 2020
30. Sun L-H, Zhang Y-M, Shang K, Wu A-B (2019) Investigation on musculoskeletal disorders of the workers in automobile production logistics. In: Proceeding of the 24th international conference on industrial engineering and engineering management 2018, pp 491–498
31. Deros BM, Khamis NK, Mohamad D, Kabilmiharbi N, Daruis DDI (2014) Investigation of oil palm harvesters' postures using RULA analysis. In: 2014 IEEE conference on biomedical engineering and sciences (IECBES)