Digital Human Modeling in Ergonomic Risk Assessment of Working Postures using RULA

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Abstract

Digital Human Modeling (DHM), the process of CAD representation of human body form, is an emerging tool used to simulate workplaces in order to provide solutions for ergonomics related problems. Digital humans/manikins are being incorporated in the software, can be manipulated easily and assessed for work related discomfort, injuries and workplace design. Manual workers in small scale industries are often exposed to work related discomfort and pain while performing work. These exposures may lead to development of work related musculoskeletal disorders (WRMSDs) and low back pain (LBP), affecting the efficiency of workers and productivity of the industry. The main objective of current study is to analyze the working postures of manual workers in small scale industries by using Rapid Upper Limb Assessment (RULA) assessment in CATIA V5R20 software. The workers in stone cutting and polishing industry were selected, and found to be working in awkward postures involving heavy manual lifting, bending, twisting and turning of the trunk. Most of the postures indicated a high risk score of 7, indicating changes in the posture to be done immediately. Ergonomic interventions were suggested and the improved posture was evaluated using RULA and the posture indicated a score of 3, indicating low risk. The manual lifting task was also assessed using NIOSH lifting equation at the origin and destination of lift, using CATIA V5R20. The ergonomic interventions reduced the value of lifting index from 1.79 to 0.98, indicating safe limit. The results indicate that awkward working posture risks can be minimized by effectively using ergonomic interventions.

Keywords
Digital Human Modeling, RULA, Work-Related Musculoskeletal Disorders, Posture, CATIA

1.0 Introduction

Ergonomics is the study of the interaction between people and machines and the factors that affect the interaction. A number of factors play a significant role in ergonomics, and these factors help to determine the safety, comfort, health and efficient performance at work place and in everyday life. Ergonomics seeks to minimize adverse

effects of the environment upon people and thus enables each person to maximize his/her contribution to a given job Qutubuddin et.al. (2013).

Workers in industries are exposed to pain and discomfort in work, leading to development of Musculoskeletal disorders (MSDs) over a period of time, and these are the most prevalent issues especially in the unorganized or informal sector. Frequent and repetitive activities with awkward or unnatural postures like bending, twisting, stretching, contact stress and vibration are some of the risk factors. Manual material handling tasks which involve transporting or supporting load including pushing, pulling, lifting, lowering, carrying or moving a load causes awkward postures due to heavy workload and exertion. These are the signs of the ergonomic hazard and may lead to reduced capacity and disability over the years, if not corrected early. According to OSHA, the physical stress on the workers can be reduced by adapting the job, workstation, equipment and tools which fit the worker, thus eliminating several work related musculoskeletal disorders (MSDs).

1.1 Ergonomic Risk Factors

Several risk factors related to the work activity and ergonomic issues make it difficult for the worker to maintain a good balance between fatigue and his ability to recover from this fatigue. A significant key to maintain this critical balance is the relationship between human factors and the work itself. Any absence of this balance increases the probability of the workers developing musculoskeletal disorders. In order to prevent this to happen, some workplace ergonomic factors are to be considered; like high work repetition, forceful exertions and sustained/repetitive awkward working postures. High work repetition, when it is combined with other risk factors such as high force or/and awkward posture, may lead to formation of MSDs. Most of the work/tasks require high force loads on the body. Muscle effort increases in response to high force requirements, increasing related fatigue, which leads to MSDs. Sustained/repetitive awkward postures place excessive force on joints and overload the muscles and tendons around the effected joint. Risk of MSDs is increased when the joints are worked outside the mid-range motion of the joint repetitively or for sustained period of time without recovery time, Mark Middlesworth (2018). To overcome these ergonomic risk factors several control methods are adapted such as engineering controls, administrative/work practice controls and encourage the use of personnel protective equipment.

1.2 Postural Analysis

A Large number of comprehensive studies can be found in literature on analysis of risks in awkward postures by ergonomic assessment tools such as RULA, REBA, QEC, NIOSH lifting equation etc. The main objective of such studies is elimination or reducing the risks of MSDs due to working in awkward postures. Another objective in such studies is to find the anthropometric mismatches between the worker and workstation design to lower the risks of MSDs and improve productivity. Some of the typical studies reported in literature using the ergonomic assessment tools RULA and REBA are on weaving workstations (Alireza et.al. 2007), on automotive components manufacturing (Baba Deros et.al 2010), on foundry worker by (Singh L.P. 2010), on workers in brick manufacturing (Qutubuddin et.al 2013), on workers in small scale industries, on manual workers in packaging section of Polypropylene yarn industry (Kabilmiharbi and Selamat 2016), Somnath and Dev (2014) studied the problems in SSIs and suggested ergonomic interventions for reducing the risk of MSDs. It is observed from the various studies that a relationship exists between the ergonomic risk factors, working postures and development of MSDs. The various methods available are used by researchers and ergonomists in identifying the risky postures, the level of risks and suggest measures for reducing the risks.

1.3 Digital Human Modeling and Simulation as Ergonomic tools

Digital Human Model (DHM) and Virtual Ergonomics are rapidly emerging as enabling technologies, promising to change how products or systems are designed, how ergonomic analyses are performed, how impairments or disorders are assessed, and how certain therapies or surgeries are conducted (Rajesh and Srinath 2016).

Literature studies show a number of ergonomics tools have been developed to assess the working postures, physiological, cognitive and biomechanical demand, and man-machine productivity analysis. Ergonomic tools such as RULA and NIOSH lifting equation have been incorporated in softwares like CATIA and ProE, 3 Dimensional Static Strength Prediction Program (3DSSPP) etc. Digital Human Models and simulation tools are considered to facilitate proactive ergonomic investigations. The DHM technology implementation allows the ergonomist for early and easier identification of ergonomic issues, and reduces or sometimes eliminates the need for physical and real human operator testing. DHM technique has been developed to facilitate ergonomic design and evaluation for a

specific human population. It gives a 3D visualisation of worker being involved in tasks/activities and provides guidelines for ergonomic analysis and workstation design. The functions of DHM are many, which include the ability to move human manikin in predefined motion, postural analysis, reach analysis, carrying analysis, push/pull analysis, RULA analysis and the provision to scale 3D manikin by available anthropometry data.

Anthropometry is one of the significant aspects to be considered in DHM. To determine the size and shape of the manikin in the simulation process, different databases are incorporated. In most DHM softwares option is available for choosing the manikin according to percentiles like 5th, 50th and 95th percentile, according to the stature and weight of certain gender, nationality etc. from the anthropometric data. Some software has provision to custom build and defines the desired anthropometric dimensions of the population. As it can be found the work force is diversified in different parts of the world, it becomes significant to design the workstation according to the anthropometry of users.

Some of the examples of use of DHMs and simulation in ergonomic assessments can be quoted from literature, such as Binoosh et.al (2017) on virtual postural assessment of an assembly of submersible pump in small scale industry, Kamat et.al (2017) reported a study on body postures on repetitive and heavy lifting in aerospace manufacturing warehouse using RULA analysis in CATIA V5. Atef et.al. (2017) conducted a study to evaluate workstations in mechanical manufacturing by using RULA and REBA in CATIA software. Similarly Deepak and Prasad (2015) reported a study on ergonomic assessment, redesign and evaluation of crane cabin using CATIA V5 software. Yayan et.al (2018) analysed the postures of workers at a workstation in a chemical industry, conducted simulations using CATIA to evaluate the design of conveyor, jack adjustable table and overall work method. Roberto et.al (2011) presented a study of street stall having reduced space for keeping goods. The stall was modelled with CATIA software which resulted in reduction of muscular tension provoked by inadequate positions.

2.0 Methodology

2.1 Rapid Upper Limb Assessment

McAtamney and Corlett (1993) developed the RULA tool for risk assessment of upper limb disorders. The tool provides a fast assessment of the posture of the upper limbs, neck and trunk. It also considers the muscle functions and load on the body. The RULA assessment generates an action category list with a code which indicates the intervention level necessary to reduce the risk of the workers discomfort. The tool provides a single score of the entire task which rates the posture, movement and force required. The scores are then grouped into four action categories that give an indication when a risk control action should be initiated.

2.2 NIOSH Lifting Equation

The revised NIOSH Lifting Equation (Waters et.al. 1993) is a method developed to provide a way to quantify the risk associated with repeated lifting task which causes low back disorders. The equation considers the task variables and establishes safe lifting guidelines and practices. Recommended Weight Limit (RWL) defines the maximum acceptable weight that all the healthy workers can lift during an eight hour shift without increasing the risk of MSD to the lower back. The RWL decides whether the weight to be lifted is too heavy for the task.
The NIOSH equation uses a load constant (LC) with a value of 23 kgs. i.e. the maximum weight to be lifted or lowered under perfect conditions. The equation then uses several variables for each task expressed as multipliers or coefficients. (In the given equation, 'M' is a multiplier) that tends to reduce the load constant to get a value of RWL for a specific lifting task.
RWL= LC (23) x HM x VM x DM x AM x FM x CM

The task variables necessary to calculate RWL are;
H = Horizontal location of the object in relation to the body
V = Vertical location of the object in relation to the floor
D = Vertical distance of the object moved
A = Asymmetry angle or Twist of body
F = Frequency and duration of lifting activity
C = Coupling or quality of the workers grip on the object being lifted

Lifting Index (LI): Lifting Index provides an estimate of the MSD risk and physical stress related with the manual lifting tasks evaluated. The lifting index gives the significant level of risk.

> Lifting Index LI = Actual Load Weight/RWL
> LI < 1= Low Risk
> LI > 1< 3 = Mild /Moderate Risk
> LI > 3 = High Risk

As the Lifting Index increases, the risk of lower back disorder increases correspondingly. The purpose is to design the lifting tasks to achieve a LI of less than 1.0.

2.3 Digital Human Modeling in CATIA

In the present study, CATIA software is selected for RULA assessment method to analyze the awkward working postures of the selected workers. The photographs of the working postures taken from the industries were converted using Computer Aided Three-dimensional Interactive Application (CATIA) software, to conduct RULA analysis. The postures of the workers were recorded from the mid-sagittal plane view. Later, RULA analysis was done on the manikin with exact replication to assess the workers postural discomfort level (Baba Deros et.al. 2013).

Posture Analysis

To identify the severity of a posture, postural analysis was carried out by RULA method. RULA method examines the severity of the risk factors and combines all the risk factors to give a total score that varies between 1 and 7. The RULA final scores are displayed by a color code in CATIA. The color changes from green for a level of 'negligible risk' to red for a level of 'high risk according to the final scores obtained. Green color is an indication of acceptable posture (final score of 1 and 2), if it is not repeated for long durations. The final scores 3 and 4 (Yellow color) is an indication that further investigation is required and changes in posture may be likely in future. The Orange color (final score 5 and 6) is an indication that further investigation is necessary and the posture should be changed soon. The final score of 7 (Red color) is an indication that investigation is necessary and change the posture immediately. The color codes are shown in figure

Segment	Score Range	Color associated to the score					
		1	2	3	4	5	6
Upper arm	1 to 6	green	green	yellow	yellow	red	red
Forearm	1 to 3	green	yellow	red	gray	gray	gray
Wrist	1 to 4	green	yellow	orange	red	gray	gray
Wrist twist	1 to 2	green	red	gray	gray	gray	gray
Neck	1 to 6	green	green	yellow	yellow	red	red
Trunk	1 to 6	green	green	yellow	yellow	red	red

Figure 1.Color code in CATIA-V5 and RULA Score

3.0 Results and Discussion

A preliminary survey was carried out to assess the ergonomic problems and prevalence of MSDs among the workers in small scale industries in North Karnataka. The region consists mostly of industries in clusters like pulse processing, stone cutting & polishing, brick making, saw mills and other industries. In most of these SSIs, the work activities involve manual work and the workers are prone to risks of developing MSDs as they work in quite unnatural postures involving bending, twisting, stretching, and heavy lifting and lowering of loads. The present study focuses on the working postures in stone cutting and polishing industry. The risk assessment of working postures is carried out by Rapid Upper Limb Assessment tool.

The Working Process: The lime stones are extracted from stone quarry by cutting the large slabs of stones into required dimensions. The workers pick up the stones manually from the point and carry it to a distance for loading into vehicles to be transported to polishing industries. In the polishing industries, the lime stones are unloaded and

stored for processing further. The operators at the polishing industry carry the stone manually from the point of storage to the polishing machine, load on the machine, process it and unload from the machine and carry manually to a point of storage of finished product. During this entire process, the workers are subjected to awkward postures like bending, lifting, lowering, carrying, stretching, pulling, pushing etc. leading to developing of risks for MSDs.

An initial survey by observations and discussions with the operators and supervisors revealed the prevalence of work related musculoskeletal problems, discomfort and pain among the workers. Hence the present study is taken up.

Criteria for selection

The criteria considered for selection of the workers were as follows:

- The workers were employed for at least one year prior to commencement of study
- All were healthy and none of them were suffering from diseases or ailments.
- The workers sample postures were representative of the respective occupation.
- The objectives of study were explained to the workers and their consent was taken to use photographs in academic publications.

The observations made through a preliminary survey of the stone cutting and polishing industry by questionnaire and discussions are given in Table 1. This was done to understand the nature of work and problem areas in the working process. The worker complaints were mainly related to experiencing discomfort in carrying out the tasks especially in the upper back, neck, shoulder and lower back. The workers also mentioned about the heavy lifting and lowering of stone slabs. After detailed analysis the worker complaints and possible problem areas are highlighted in the Table.1. As can be seen, Postural discomfort and MSD problems are high in the industry.

Table 1. Workers Complaints on Ergonomic aspects in Different Occupations

Occupation	A*	B*	C*	D*	E*	F*	G*
Stone Cutting & Polishing	High	High	Moderate	Moderate	Low	Very high	Moderate

***A**-MSD Problems, **B**-Postural Discomfort, **C**-Heat Stress, **D**- Health and Hygiene, **E**-Time Pressure, **F**-Noise, **G**-Any other (dust, vibration)*

RULA Analysis in Stone Quarry

About 32 working postures from the stone cutting and polishing industry were randomly selected for RULA analysis. The postures were so chosen that they represent the entire working activities in the industry. The postures were selected from manual cutting, machine cutting and polishing workers. The loading and unloading activities of lime stone slabs, lifting and lowering activities, working postures of operator on polishing machine, cutting and grinding machines were chosen. The Human Body Modeling was done in CATIA using the Anthropometry measurements of the Indian workers and manikins were created. The input data for RULA analysis was collected for the respective postures such as the angles made by the body members (upper arm, lower arm, wrist, wrist twist, neck, trunk, legs and muscle use).

The RULA scores obtained are shown in Table 2, and Figure 2, respectively. As can be seen from Table 2, not even a single posture has negligible risk. About 15.6% of postures have a low risk category, which indicates further investigation and a change may be made in future. In the medium risk category 34.4% fall indicating further investigation and early change in the postures. The machine operators, grinding workers and other workers doing miscellaneous activities mostly belong to this category. The RULA scores indicate that about 50% of the working postures are in high risk category, signaling these postures to be investigated further and change the postures immediately, to avoid further development of MSDs and even loss of function. The postures in manual cutting are about 57.2% in high risk category. This may be due to heavy manual lifting involved and repetitive motions. The severe/awkward postures are mostly exhibited by workers doing loading-unloading activities, manual material handling activities like lifting, carrying and lowering of heavy stone slabs and the polishing machine operators subjected to awkward postures and vibrations of machines.

Table 2. RULA analysis final scores of postures in stone cutting and polishing units (n=32)

RULA score	Work Activity/Process No. of postures (percentage)				Risk Level	Action to be taken
	Manual Cutting	Machine Cutting	Cutting & Polishing	Total (%)		
1-2	0	0	0	0	Negligible	Acceptable posture if it is not repeated for longer period
3-4	1 (14.3)	2 (16.7)	2 (15.4)	5 (15.6)	Low	Further investigation and change may be needed in future
5-6	2 (28.6)	4 (33.3))	5 (38.5)	11 (34.4)	Medium	Investigation required and change needed soon
7	4 (57.2)	6 (50)	6 (46.1)	16 (50.0)	High	Investigate posture and change needed immediate
Total	7	12	13	32		
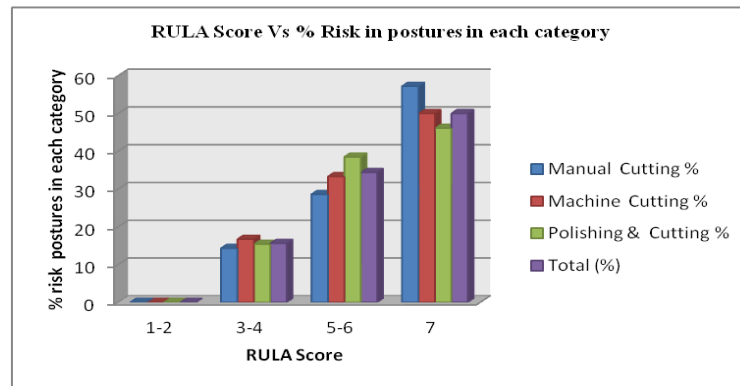
Figure 2. RULA score in different processes indicating % of risky postures

RULA analysis in manual cutting

Some of the worst working postures of the workers while performing the tasks in stone quarry are selected in Figure 3(a) and 3(b). The actual pictures of the workers are converted in CATIA software V5 for Rapid Upper Limb Analysis. The postures selected are prone to developing musculoskeletal disorder risks (MSD). In figure 3(a) the work involves removing the thick stone from the quarry, which has been previously marked and cut. After removing the stone which is about 5 to 6 inches in thickness, it is reduced to about 1 inch thick manually by the operator using hand tools. The worker then lifts the stone to be carried to point of storage. The RULA score for this posture is 7, as the posture requires bending, stretching, lifting heavy loads etc. In figure 3(b), the worker is seen carrying the heavy stone at a distance of about 10 to 15metres and keeping it on the ground to be moved in vehicles to the polishing units later. The posture involves heavy lift above shoulders, bending forward to lift and lower the loads. The weight of the stones is up to 20 kgs, depending on the size and thickness. The RULA analysis score for this posture is as well 7, indicating high risk and change immediately. The posture involves heavy lift above shoulders, bending forward to lift and lower the loads. The weight of the stones is up to 20 kgs, depending on the size and thickness. The RULA analysis score for this posture is as well 7, indicating high risk and change immediately. The postural risks in similar postures as shown in figure 3(a) and 3(b) can be brought down by low cost ergonomics interventions. As these postures involve a major part of lifting, carrying and lowering loads, a push cart with scissor lift is suggested. It is recommended to have two workers loading the stone slabs into the push cart. The suggested improvement is modeled in CATIA and it is seen that the RULA score is brought down to 3 and 4, indicating medium risk, as shown in figure 3(c).
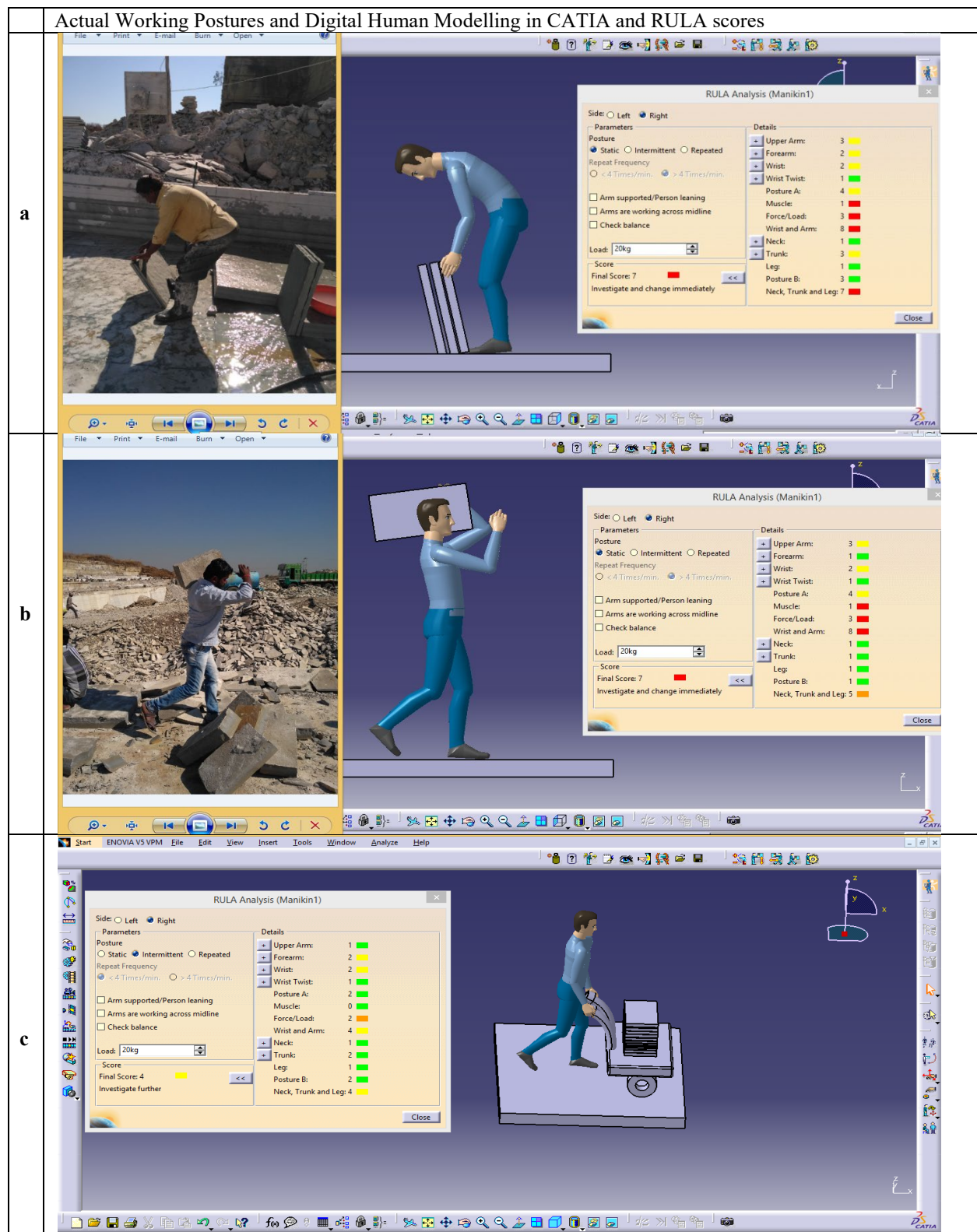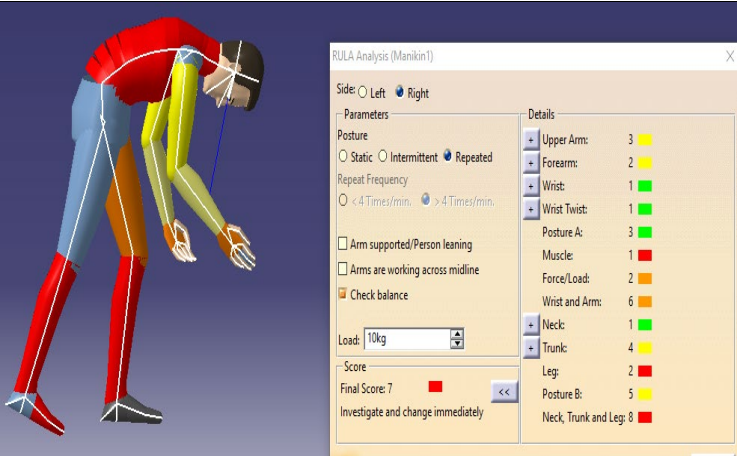
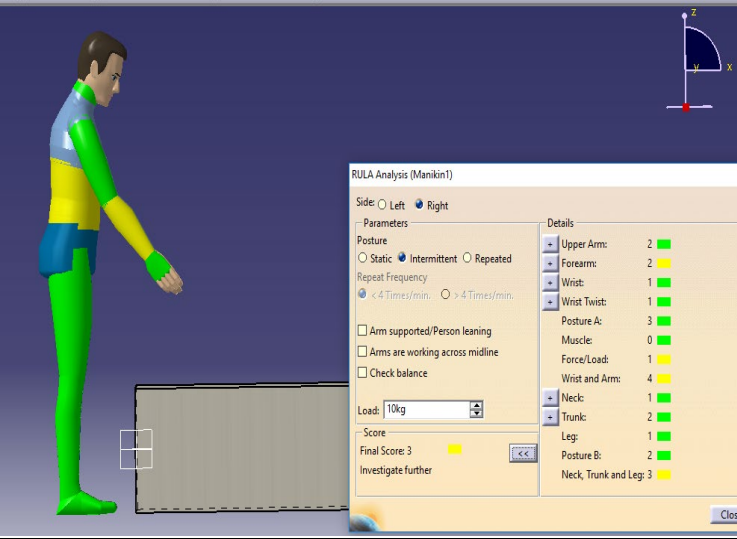|	Actual Working Postures and Digital Human Modelling in CATIA and RULA scores
a	
b	
c	

Figure 3.Actual Working Postures and Digital Human Modeling in CATIA and RULA scores (a) and (b), showing improvement with ergonomic intervention (c), in stone quarry.

RULA analysis in Polishing Unit

The postures shown in figure 4(a) and 4(b) corresponds to work in stone polishing units. In polishing industry, the machine operator is picking a stone from the floor, and carries it to the polishing machine at a distance of about 5-10 metres, loads the stone slab on the machine, completes the polishing work, then the stone is removed and carried to a distance for storage. The company does not have workers for manual material handling. The machine operator himself has to perform all the activities. As seen from figure 4(a), the operator bends forward to lift a stone from the floor and carry it to the machine. The awkward posture requires forward bending of the trunk, upper arm and shoulders. The RULA analysis score for this posture is 7, indicating high risk and posture to be changed immediately. It is suggested to improve the upper arm, neck and trunk posture so that the RULA score is reduced. Engineering interventions were suggested for this activity by building a platform at an approximate height of about 45 cms. The platform can be used for storing the stone slabs brought from the stone quarry. in the new improved method, a trial is made by temporarily making a platform and asking the operators to pick stone slabs from the platform. The new posture as shown in figure 4(b) and 4(c) is analyzed using RULA. The final score for this improved posture comes to 3 and 4, which indicates medium risk category.

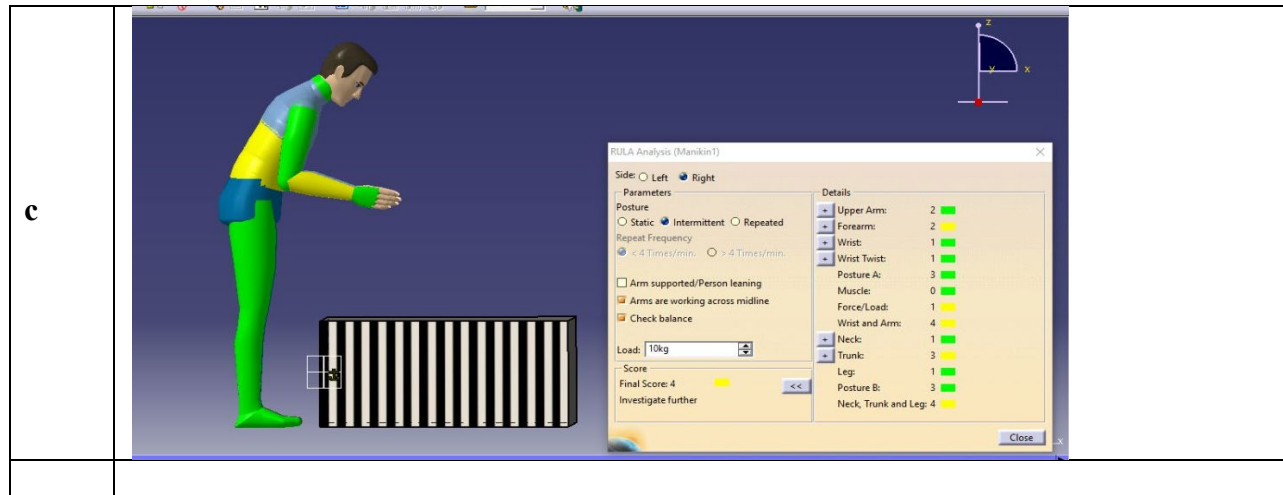| Posture	Actual Working Posture	Digital Human Model and RULA analysis in CATIA
a		
	Final score of the posture by RULA analysis '7'	
b		
	Final score of the posture by RULA analysis '3'	

c	

Figure 4. Actual Working Posture (a) and (b), and Digital Human Model of each Posture with RULA analysis score (c), in stone polishing unit.

NIOSH Lifting Equation
The NIOSH lifting equation was used to find out the Recommended Weight Level and value of Lifting Index. The various variables were measured like weight of load lifted, horizontal distance (H), vertical distance(V), the frequency of lift(F), coupling (C) and Asymmetry angle (A), and the distance moved (D) both at the origin and destination of lift.
The multipliers were calculated from the variables as follows;
1) The horizontal multiplier (HM) = 10/H. 2),   2) The vertical multiplier (VM) = $(1 - (0.0075|V - 30|))$.
3) The distance multiplier (DM) = $(0.82 + (1.8/D)$, 4) The asymmetric multiplier (AM) = $(1 - (0.0032A))$.
5) The frequency multiplier (FM) from NIOSH lifting Table 1, 6) The coupling multiplier (CM) from NIOSH lifting Table 2. , The Recommended Weight Limit (RWL) is then calculated by multiplying all multiplier with the load constant (LC) 23 kgs. Finally, the lifting index (LI) was calculated by dividing the RWL with the weight of object lifted.
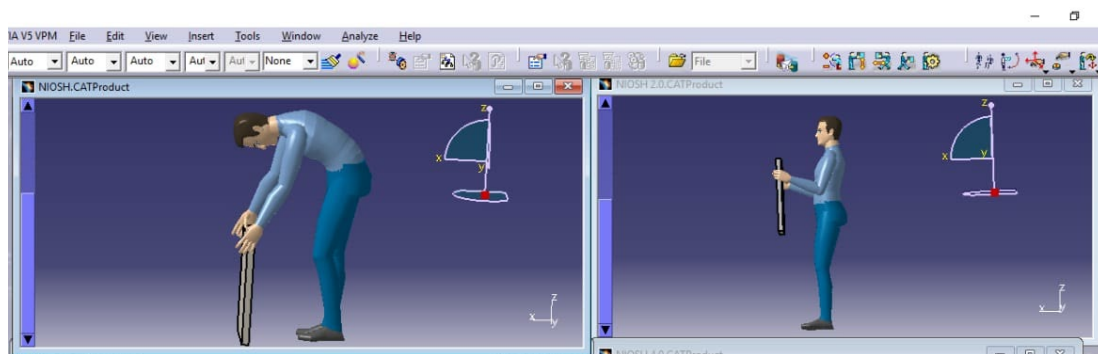

Figure 5. Lifting of stone slabs in the present condition

The present lifting involves the polishing machine operator, with both the directly in front of the body lifts the lime stone slab in the hands. The posture requires forward bending to lift the stone from the floor. The operator stands with the load in his hand to be carried to the polishing machine. The task variables are measured. For this activity the coupling is classified as fair, as the workers must position his hands around the object and should have a significant control of the object at the destination. The RWL is calculated both at the origin of lift and the destination, as shown in figure 5. The value of RWL at the origin is 1.64 and 1.79 at the destination. The weight to be lifted (15kgs) is more than the RWL calculated at the origin and the destination of the lift. The values of Lifting

Index indicate that the task is slightly stressful to the operator at the origin and moderately stressful at the destination.
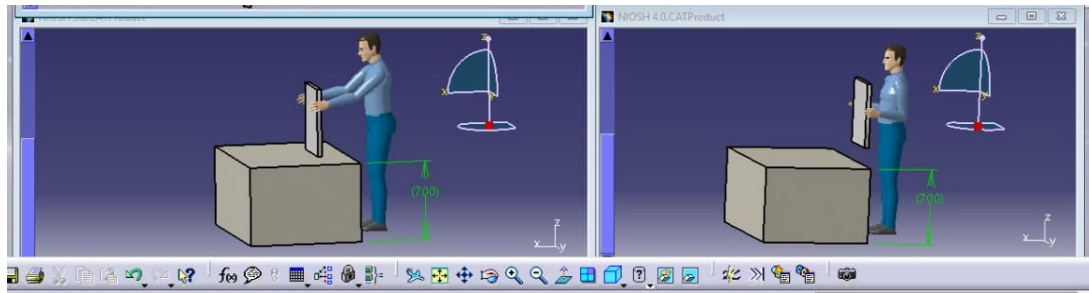

Figure 6. Lifting of stone slabs in the improved condition

In order to reduce the value of lifting index and hence reduce the risks of low back pain and injuries to the operator, ergonomic redesign of the task is necessary. The measures taken to reduce the value of lifting index are 1) To adapt a push cart or trolley to carry the stone slabs. 2) Modifications of the variables are suggested. 3) Raising the height of the place at origin by building a platform**.** The changes made are shown in figure 6 above. With the necessary changes in the workplace the lifting index value is 1.2 at the origin of lift and 0.98 at the destination. A lifting index value of less than 1 indicates the lifting load is safe for the operator.
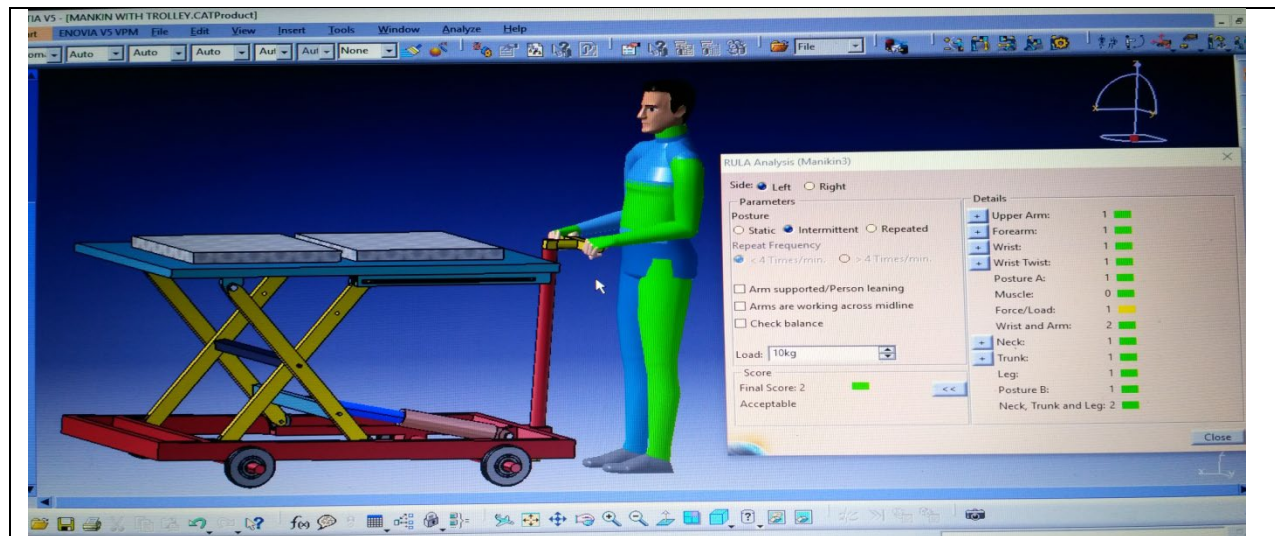

Figure 7. Recommendation of height adjustable scissor lift trolley/push cart

Conclusion

Digital Human Models and simulation have emerged as significant tools to facilitate proactive ergonomic investigations. The DHM technologies have allowed the ergonomist to early identification of ergonomic issues, and reduce or eliminate the need for physical and real human operator testing.

Based on the results obtained from the studies conducted in the stone quarry and stone polishing industries, the working postures practiced by the workers while performing tasks are risky and unsafe. More workers are required to work in unsafe conditions handling heavy loads repetitively. The RULA method used to analyze the working postures indicated that about 57% postures in manual cutting, 50% postures in machine cutting and 46% postures in polishing units are in high category requiring further investigation and immediate change. Some of the postures were modeled in CATIA V5 to find out the risk levels, and the improvements were suggested based on CATIA results. In one case of lifting of heavy stone slabs in stone quarry, the RULA score is reduced to 3and 4 indicating medium risk, by incorporating engineering controls. Similarly in the polishing unit the RULA score for some postures is 7 in

the high risk category. This can be brought down by incorporating ergonomic design of the workplace and hence the RULA score in reduced to 3 and 4. To determine the risks of workers to lower back pain and discomfort, NIOSH lifting equation was used to calculate the recommended weight limit and lifting index. In a particular case, the value of lifting index was brought down from 1.79 to 0.98, indicating safe limits. Overall the work in stone quarry and stone polishing units involves manual work with less amount of mechanization. It is suggested to use push carts and trolleys for movement of heavy stone slabs. For lifting and lowering the stone slabs it is recommended to encourage team lifting by two or more persons to reduce the stress on the workers. An example of the suggestion made is shown in figure 7, the use of push cart with a scissor lift so that the height of the trolley can be raised or lowered. This helps in avoiding the forward bending and heavy lifting of the operators. Also the use of such trolley reduced the RULA score.

References

Alireza Choobineh, Mostafa Hosseini, Mohammadali Lahmi, Reza Khani Jazani, Houshang Shahnavaz., Musculoskeletal Problems in Iranian Hand-Woven Carpet Industry: Guidelines for workstation design, *Applied Ergonomics* Vol. 38, pp. 617–624, 2007

Atef Boulila, Mahfoudh Ayadi, Khadija Mrabet, Ergonomics study and analysis of workstations in Tunisian mechanical manufacturing, *Human Factors and Ergonomics in Manufacturing & Service Industries,* vol.(28) (4) pp.166-185, 2018

Baba Md. Deros, Dian Darina Indah Darius, Ahmad Rasdan Ismail, Nurfarhana Abdullah Sawal and Jaharah A Ghani., Work-Related Musculoskeletal Disorders among Workers' Performing Manual Material Handling Work in an Automotive Manufacturing Company, *American Journal of Applied Sciences* 7 (8) pp. 1087-1092, 2010

Deepak Kumar Kushwaha, Prasad V.Kane, Ergonomic Assessment and workstation design of shipping crane cabin in steel industry, *International Journal of Industrial Ergonomics*, vol.(52), pp.29-39 2016.

Kabilmiharbi, N, Selamat, F.E., Rula Analysis of Work-Related Musculoskeletal Disorder among Polypropylene Fibrillated Yarn Industry Worker Using Digital Human Modelling (DHM), *Malaysian Journal of Public Health Medicine, Special volume (1), pp.53-60, 2016*

Lynn McAtamney and E Nigel Corlett., RULA: a survey method for the investigation of world-related upper limb disorders, *Applied Ergonomics,* 24(2), pp.91-99, 1993

Mark Middlesworth, Ergonomic Risk Factors available at,https://ergo-plus.com/ergonomic-risk-factors/

Qutubuddin S.M., Hebbal S.S, ACS Kumar., Computer Assisted systems for Enhancing the Application of Ergonomics in Manufacturing Systems', *International Journal of Ergonomics (IJEG)* , Malaysia. Volume 2, No.1, pp. 1-11, April 2012

Qutubuddin S.M., Hebbal S.S, ACS Kumar., Ergonomic Risk Assessment using Postural Analysis Tools in a Bus Body Building Unit, *Industrial Engineering Letters,* Vol 3, No 8,pp 10-20, 2013

Qutubuddin S.M., Hebbal S.S, ACS Kumar - 'An ergonomic study of work related musculoskeletal disorder risks in Indian Saw Mills', *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE),* Volume 7, Issue 5 , pp 07-13, 2013

Rajesh Raghunathan, Srinath, Review of Recent Developments in Ergonomic Design and Digital Human Models, *Industrial Engineering and Management,* 5:186 Volume 5, Issue 2, pp 1-7, 2016

Roberto Pradanos, Juan Manuel Sanz, Daniel Gutierrez, Nerea de la Puente, Jose Ignacio Rojas, Manuel Dominguez, Maria del Mar Espinosa, Ergonomic design and analysis of a post in a stall, *Proceedings of the IMProVe 2011, International Conference on Innovative Methods in Product Design, June 15-17, 2011.*

S.R.Kamat, N.E.N.Md.Zula, N.S. Rayme, S.Shamsuddin and K.Husain, The ergonomics body posture on repetitive and heavy lifting activities of workers in aerospace manufacturing warehouse, *IOP Conference Series: Materials Science Engineering 210*, pp 1-12, 2017.

S.A.Binoosh, G.Madhan Mohan, P.Ashok, K.Dhana Sekaran, Virtual postural assessment of an assembly work in a small scale submersible pump manufacturing industry, *Work*, (58), pp.567-578, 2017

Singh L.P, Work Posture Assessment in Forging Industry – An Exploratory Study in India, *International Journal of Advanced Engineering Technology,* Vol.I .Issue III, pp.358-366, 2010

Somnath Gangopadhyay and Samrat Dev, Design and Evaluation of Ergonomic Interventions for the Prevention of Musculoskeletal Disorders in India, *Annals of Occupational and Environmental Medicine*, 26:18, pp 1-6, 2014.

Thomas R Waters, Vern Putz Anderson, Arun Garg and Lawrence J Fine., Revised NIOSH equation for the design and evaluation of manual lifting tasks, *Ergonomics* 36 (7), pp.749-776, 1993

U.S.Department of Labor, Occupational Safety and Health Administration, Ergonomics: The Study of Work
2000 (Revised) www.osha.gov
Yayan Harry Yadi, L.Meily Kurniawidjaja, Indri Hapsari Susilowati, Ergonomics Intervention Study of the
RULA/REBA method in Chemical Industries for MSDs' Risk Assessment, in *International Conference on
Occupational Health ans Safety (ICOHS-2017), KnE Life Sciencies,* pp.181-189, 2018

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