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Research Article

Analysis of Weight Distribution in Terms of Forces and Torques during Lifting Weight Using Digital Human Modelling

Zafar Ullah*and Shahid Maqsood

University of Engineering and Technology, Peshawar 25000, Pakistan

ABSTRACT

Construction activities performed by workers are usually repetitive and physically demanding. Execution of such tasks in awkward postures can strain the body parts and can result in fatigue, back pain or in severe cases permanent disabilities. In view of this Digital Human Modelling (DHM) technology offers human ergonomics experts the facilities of an efficient means of kinematics characteristics of lifting heavy weights in different postures. The objective of this paper is to analyse and calculate the forces and torques on the different body parts during lifting weights in four different postures using Digital Human Modelling software. For this purposes four different lifting postures were analysed and the forces and torques were calculated. It was identified that changing the postures considerably minimize the redundant stresses on the body muscles.

Keywords: Musculoskeletal disorders; Lifting task; Lower back pain

INTRODUCTION

The International Labour Organization (ILO) estimates that some 2.3 million women and men around the world succumb to work-related accidents or diseases every year; this corresponds to over 6000 deaths every single day. Worldwide, there are around 340 million occupational accidents and 160 million victims of work-related illnesses annually [1]. Over the years, manufacturing companies have taken ergonomics and usability as basic parameters of quality for their products [1].

The design approach has been reviewed, giving to the end-users' needs, requests, and limitations an extensive consideration. For this reason, an increasing attention is currently devoted to ergonomics and human factors evaluations even from the early stages of the design process [2-4]. Digital Mock-Ups (DMUs) provided by many computer aided engineering applications enable manufacturers to design a digital prototype of a product in full details, simulating its functions and predicting interaction among its different components [5-8]. The production of physical prototypes, which is a very time consuming task, is then deferred to the final stages of the design process [9]. In order to take advantage of digital simulations to conduct ergonomic assessments (computer aided ergonomics), digital substitutes of human beings capable of interacting with the DMUs in the simulation environment are required [10,11].

This has given birth to the so- called Digital Human Modelling (DHM), which led to the development of many software tools [10,12,13]. These tools are mainly used to study human-product and human-process interaction and to conduct ergonomic and biomechanical analyses, as well as manual process simulations, even before the physical prototype is available. DMUs, together with digital human models, are increasingly used in order to reduce the development time and cost, as well as to facilitate the prediction of performance and/or safety [14]. The ergonomic design methodology relying on digital human models makes the iterative process of design evaluation, diagnosis and review more rapid and economical [15,16]. It increases also the quality by minimizing the redundant changes and improves safety of products by eliminating ergonomics related problems [17,18]. Furthermore, with the arising of the forth-industrial revolution (Industry 4.0), the concept of the virtualization of the manufacturing processes has gained a greater importance. In this context, human simulation in production activities will certainly play a significant role [19]. These digital humans, provided by many process simulation software, are essentially kinematic chains consisting of several segments and joints [20]. In view of this the digital human modelling software helps to construct the

Correspondence to: Ullah Z, University of Engineering and Technology Peshawar 25000, Pakistan, Tel: +92 03329278262; E-mail: zafarullah631@yahoo.com

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human replica within the software and analysis is made on the mannequins in lifting task to calculate the forces and torques.

METHODOLOGY

Digital human models are computer-generated prototype of human beings used for biomechanical analysis. The mannequins are design through Human Computer Aided Design (CAD) software to mimic the real life industries workers posture. The facility of Ergo Tool is also available in the software which provides the static biomechanical stress on the different body parts. Four different lifting postures were analysed for forces and torque calculation assigning 20 kg concrete block to be lift.

MANNEQUIN POSTURE DURING LIFTING WEIGHT

The mannequins were assigned 20 kg weight to be lift in four different postures. Through Ergo Tool in Human Cad Mannequin Pro were applied to calculate the forces and torques applied on different body parts. Mannequin in Figure 1, picking the 20 kg load in semi standing forward bending position, in Figure 2 picking the same load in semi sitting position with align knee and hip position with hand more extended and neck bending slightly from frontal plane. Similarly the mannequin in Figure 3, loading the load with standing feet and hand extended, the mannequin in Figure 4, picking the load with sitting position with one leg front support and one leg back support.

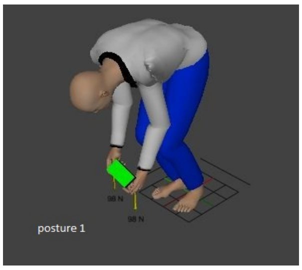

Figure 1: Mannequin lifting block sitting with head extended down.

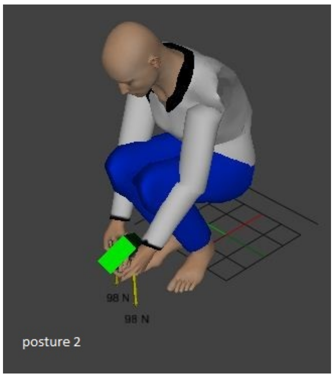

Figure 2: Mannequin lifting block in semi sitting.

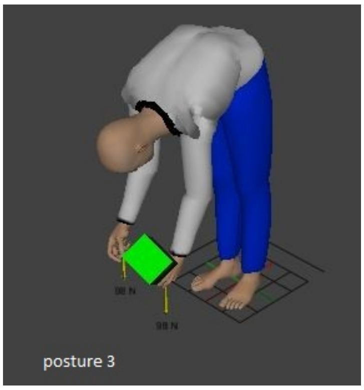

Figure 3: Mannequin lifting block with forward extension with legs straight.

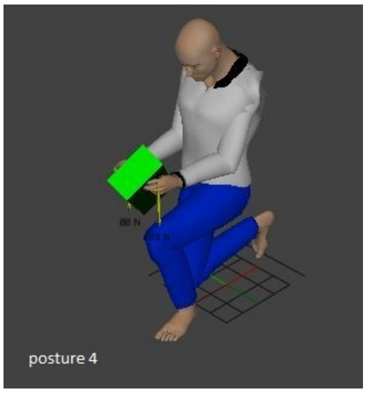

Figure 4: Mannequin lifting block with one leg back with knee support.

RESULTS OF DIGITAL HUMAN MODELLING

The detailed forces and torque is provided in the static biomechanics (Tables 1-4). The postures taken is the replica of real life workers during lifting blocks. Four mannequin were created and assign to pick 20 kg concrete block and the masses act as a weights due to gravity. In the Human CAD the Ergo tool of Static Biomechanics Tool were applied and all the forces and torque are displayed on the window screen. The details of static biomechanical stress are given in the Tables 1-4.

Table 1 shows the static biomechanical stresses on different body parts, the highest force applied on pelvis (359.049 N) and the second most load bearing region is thorax (268.708 N). Similarly the highest positive torque act on the thorax (183.927 Nm) and secondly (167.889 Nm) positive torque act on the pelvis. The line graph in Figure 5 shows that most of the stresses are concentrated on the pelvic region.

Table 1: Static biomechanical forces of posture 1.

	Force(N)	Torque(Nm)
Head	65.629	0
Left Arm	24.356	45.807
Left Foot	17.682	0.475

Left Forearm	10.518	36.547
Left Palm	7.317	9.886
Left Shank	49.872	12.144
Left Thigh	121.998	23.426
Pelvis	359.049	183.927
Right Arm	25.267	38.982
Left Foot	17.682	1.087
Right Forearm	11.429	36.206
Right Palm	105.317	9.584
Right Shank	49.872	4.817
Right Thigh	121.998	30.857
Thorax	268.708	167.889

Table 2 shows the static biomechanical stresses on different body parts, the highest force applied on pelvis (359.049 N) and the second most load bearing region is thorax (268.708 N). Similarly the highest positive torque act on the thorax (183.927 Nm) and secondly (167.889 Nm) positive torque act on the pelvis. The line graph in Figure 6 shows that most of the stresses are concentrated on the pelvic region.

Table 2: Static biomechanical forces of posture 2.

	Force(N)	Torque(Nm)
Head	65.629	0
Left Arm	24.356	51.533
Left Foot	17.682	1.147
Left Forearm	10.518	37.884
Left Palm	7.317	10.983
Left Shank	49.872	3.71
Left Thigh	121.998	32.084
Pelvis	359.049	122.721
Right Arm	25.267	41.744
Left Foot	17.682	0.468
Right Forearm	11.429	31.72
Right Palm	95.317	7.335
Right Shank	49.872	13.93
Right Thigh	121.998	3.682
Thorax	268.708	103.175

Table 3: Static biomechanical forces of posture 3.

	Force(N)	Torque(Nm)
Head	65.629	0
Left Arm	24.356	16.562
LeftFoot	17.682	1.145
Left Forearm	10.518	15.321
Left Palm	7.317	6.36
Left Shank	49.872	1.145
Left Thigh	121.998	2.777
Pelvis	359.049	103.136
Right Arm	25.267	15.674
Left Foot	17.682	1.094
Right Forearm	11.429	15.424
Right Palm	7.317	5.605
Right Shank	49.872	1.094
Right Thigh	121.998	2.626
Thorax	268.708	112.915

Table 4: Static biomechanical forces of posture 4.

	Force(N)	Torque(Nm)
Head	65.629	0
Left Arm	24.356	37.216
Left Foot	17.682	1.023
Left Forearm	10.518	26.133
Left Palm	7.317	8.598
LeftShanke	49.872	6.64
LeftThigh	121.998	26.871
Pelvis	359.049	160.717
Right Arm	25.267	29.889
Left Foot	17.682	0.965

Right Forearm	11.429	17.848
Right Palm	105.317	7.426
Right Shank	49.872	6.631
Right Thigh	121.998	26.856
Thorax	268.708	156.112

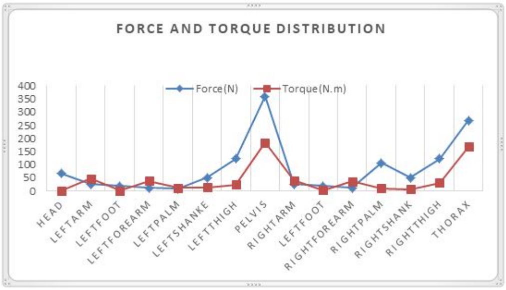

Figure 5: Static biomechanical graph of posture 1.

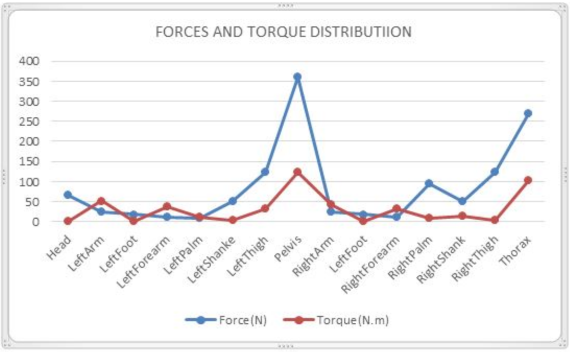

Figure 6: Static biomechanical graph of posture 2.

Table 3 shows the static biomechanical stresses on different body parts, the highest force applied on pelvis (359.049 N) and the second most load bearing region is thorax (268.708 N). Similarly the highest positive torque act on the thorax (112.915 Nm) and secondly (103.136 Nm) positive torque act on the pelvis. The line graph in Figure 7 shows that most of the stresses are concentrated on the pelvic region.

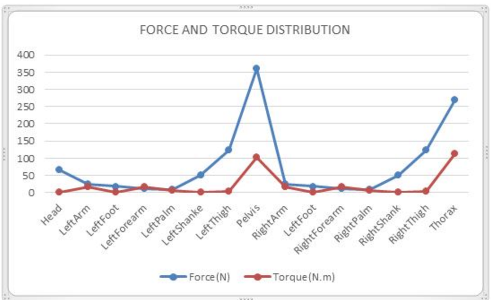

Figure 7: Static biomechanical graph of posture 3.

Table 4 shows the static biomechanical stresses on different body parts, the highest force applied on pelvis (359.049 N) and the second most load bearing region is thorax (268.708 N). Similarly the highest positive torque act on the thorax (156.112 Nm) and secondly (160.717 Nm) positive torque act on the pelvis. The line graph in Figure 8 shows that most of the stresses are concentrated on the pelvic region.

Results of forces of the four postures given in below Table 5 and comparing results of torque of the four postures given in below Table 6.

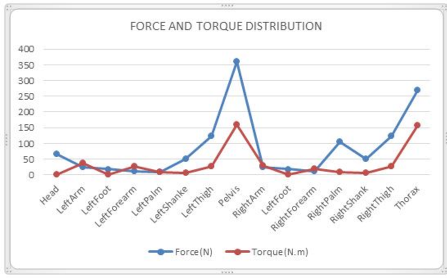

Figure 8: Static biomechanical graph of posture 4.

Table 5: Comparing Forces, comparing results of the four postures and Results of forces of the four postures.

	Figure 1 (Force(N))	Figure 2 (Force(N))	Figure 3 (Force(N))	Figure 4 (Force(N))
Head	65.629	65.629	65.629	65.629
Left Arm	24.356	24.356	24.356	24.356
Left Foot	17.682	17.682	17.682	17.682
Left Forearm	10.518	10.518	10.518	10.518
Left Palm	7.317	7.317	7.317	7.317
Left Shank	49.872	49.872	49.872	49.872
Left Thigh	121.998	121.998	121.998	121.998
Pelvis	359.049	359.049	359.049	359.049
Right Arm	25.267	25.267	25.267	25.267
Left Foot	17.682	17.682	17.682	17.682
Right Forearm	11.429	11.429	11.429	11.429
Right Palm	105.317	95.317	7.317	105.317
Right Shank	49.872	49.872	49.872	49.872
Right Thigh	121.998	121.998	121.998	121.998
Thorax	268.708	268.708	268.708	268.708

Table 6: Comparing torque, comparing the results of torque of the four postures.

	Figure 1 Torque(Nm)	Figure 2 Torque(Nm)	Figure 3 Torque(Nm)	Figure 4 Torque(Nm)
Head	0	0	0	0
Left Arm	45.807	51.533	16.562	37.216
Left Foot	0.475	1.147	1.145	1.023
Left Forearm	36.547	37.884	15.321	26.133
Left Palm	9.886	10.983	6.36	8.598
Left Shanke	12.144	3.71	1.145	6.64
Left Thigh	23.426	32.084	2.777	26.871
Pelvis	183.927	122.721	103.136	160.717
Right Arm	38.982	41.744	15.674	29.889
Left Foot	1.087	0.468	1.094	0.965
Right Forearm	36.206	31.72	15.424	17.848
Right Palm	9.584	7.335	5.605	7.426
Right Shank	4.817	13.93	1.094	6.631
Right Thigh	30.857	3.682	2.626	26.856
Thorax	167.889	103.175	112.915	156.112

DISCUSSION

Musculoskeletal Disorders are noted as a result of the presence of different risk factors, including contact stress, force, vibrations, repetition and jobs that put muscles under redundant physical forces. In the proposed study it is shown that changing the posture significantly change thee stresses. Figure 9 shows the comparative forces applied, the highest forces allied on posture 4 in Figure 4, followed by posture 3 in Figure 3. Similarly in posture 2 in Figure 2 a less forces is applied and the most ergonomically less stresses posture is in Figure 1 of posture 1. Similarly is the case of torque produced in the body is concentrated in the pelvis region. As from Figures 9 and 10, it is clear that most of the forces and positive torque is concentrated in pelvis region and the pelvis region is the most sensitive region of the human skeletal system.

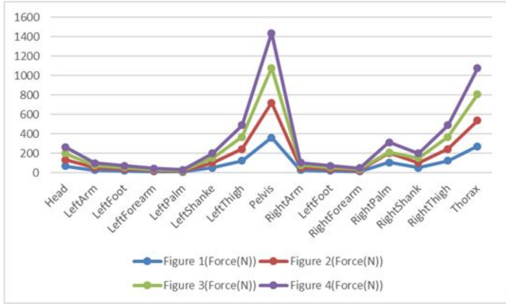

Figure 9: Static biomechanical graph of the forces.

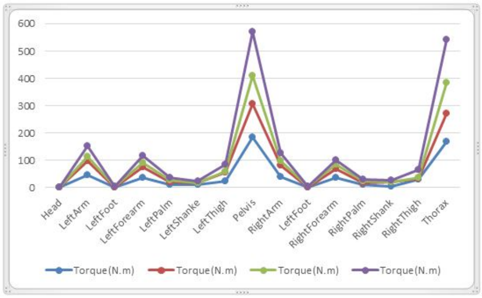

Figure10: Static biomechanical graph of the torques.

CONCLUSION

Through Human CAD tool the static Biomechanical stresses distributions were calculated. In an industrially developing countries like Pakistan the source of exposure to MSDs risks seem to be severe mainly because of the untrained workforce and due the absence of the labour laws implementation. The conclusion taken is that, though many studies have shown a significant relation between manual labour and MSDs, in an industrially developing countries, people are exposed to work without knowing the new job physical demand. In this regard, there is a dire need for medical and physical examination as a prerequisite for new jobs. In addition, workers should be trained on ergonomics basis before they are exposing to manual material handling.

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