Analysis of Weight Distribution in Term of Forces and Torques during Lifting Weight using Digital Human Modelling

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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 fourth-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
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.

**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.

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

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.
Table 2: Static biomechanical forces of posture 2.

| Body Part | Force (N) | Torque (Nm) |
|-----------|-----------|-------------|
| Head      | 65.629    | 0           |
| Left Arm  | 24.356    | 51.533      |
| Left Foot | 17.682    | 1.087       |
| Left Forearm | 10.518 | 37.884     |
| Left Palm | 7.317     | 10.983      |
| Left Shank| 49.872    | 4.817       |
| Left Thigh| 121.998   | 30.857      |
| 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 3: Static biomechanical forces of posture 3.

| Body Part | Force (N) | Torque (Nm) |
|-----------|-----------|-------------|
| Head      | 65.629    | 0           |
| Left Arm  | 24.356    | 16.562      |
| Left Foot | 17.682    | 1.094       |
| Left Forearm | 10.518 | 15.424     |
| Left Palm | 7.317     | 5.605       |
| Left Shank| 49.872    | 1.094       |
| Left Thigh| 121.998   | 2.626       |
| 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.

| Body Part | Force (N) | Torque (Nm) |
|-----------|-----------|-------------|
| Head      | 65.629    | 0           |
| Left Arm  | 24.356    | 37.216      |
| Left Foot | 17.682    | 1.023       |
| Left Forearm | 10.518 | 29.889     |
| Left Palm | 7.317     | 8.598       |
| Left Shank| 49.872    | 6.64        |
| Left Thigh| 121.998   | 26.871      |
| Pelvis    | 359.049   | 160.717     |
| Right Arm | 25.267    | 29.889      |
| Left Foot | 17.682    | 0.965       |
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 (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.

| Body Part   | Force (N) 1 | Force (N) 2 | Force (N) 3 | Force (N) 4 |
|-------------|-------------|-------------|-------------|-------------|
| 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 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).
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.

REFERENCES

1. Kaulio MA. Customer, consumer and user involvement in product development: A framework and a review of selected methods. Total Quality Management. 1998;9:141-149.
2. Stanton NA, Salmon PM, Rafferty LA, Walker GH, Baber C, Jenkins DP. Human factors methods: a practical guide for engineering and design. CRC Press. 2017
3. Shackel B. Ergonomics in information technology in Europea review. Behav Inf Technol. 1985;4:263-287.
4. Martinsons MG, Chong PK. The influence of human factors and specialist involvement on information systems success. Human relations. 1999;52:123-152.
5. De Sa AG, Zachmann G. Virtual reality as a tool for verification of assembly and maintenance processes. Computers & Graphics. 1999;23:389-403.
6. Stark R, Krause FL, Kind C, Rothenburg U, Müller P, Hayka H, et al. Competing in engineering design- The role of Virtual Product Creation. CIRP Journal of Manufacturing Science and Technology. 2010;3:175-184.
7. Dolezal WR. Success factors for digital mock-ups (DMU) in complex aerospace product development. Technische Universität München. 2008.
8. Mourtzis D, Papakostas N, Mavrikios D, Makris S, Alexopoulos K. The role of simulation in digital manufacturing: applications and outlook. Int J Comput Integ Manuf. 2015;28:3-24.
9. Whiteside J, Bennett J, Holtzblatt K. Usability engineering: Our experience and evolution handbook of human-computer interaction. Elsevier. 1998.
10. Pelliccia L, Klimant F, De Santis A, Di Gironimo G, Lanzotti A, Tarallo A, et al. Task-based motion control of digital humans for industrial applications. Procedia CIRP. 2017;62:535-540.
11. Magistris GD, Micaelli A, Savin J, Gaudez C, Marsot J. Dynamic digital human models for ergonomic analysis based on humanoid robotics techniques. Int J Digital Human. 2015;1:81-109.
12. Di Gironimo G, Pelliccia L, Siciliano B, Tarallo A. Biomechanically-based motion control for a digital human. Int J Interact Des Manuf. 2012;6:1-13.
13. De Magistris G, Micaelli A, Evrard P, Andriot C, Savin J, Gaudez C, et al. Dynamic control of DHM for ergonomic assessments. Int J Ind Ergon. 2013;43:170-180.
14. Ma L, Chablat D, Bennis F, Zhang W, Guillaume F. A new muscle fatigue and recovery model and its ergonomics application in human simulation. Virtual Phys Prototyp. 2010;5:123-137.
15. Rasmussen J. Skills, rules, and knowledge; signals, signs, and symbols, and other distinctions in human performance models. IEEE transactions on systems, man, and cybernetics. 1983;13:257-266.
16. Maguire M. Methods to support human-centred design. Int J Hum Comput Stud. 2001;55:587-634.
17. Demirel HO, Duffy VG. Applications of digital human modeling in industry. International Conference on Digital Human Modeling. Springer. (2007)
18. MacLeod D. The ergonomics edge: Improving safety, quality, and productivity. John Wiley & Sons. US. 1994.
19. Hai Z. Development of smart industry maturity model. University of Twente. Master’s Thesis. 2017.
20. Aggarwal JK, Cai Q. Human motion analysis: A review. Comput Vis Image Underst. 1999;73:428-440.