"Ergonomic Weightlifting" Competition by Using JACK

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Abstract

The main objective of this paper is to model a weightlifting process using JACK software and analyze the lifting process, in order to reduce the risk of lower back injuries for lifting tasks. As industrial engineering students our aim is to understand the hazards of lifting heavy objects in the work area and reduce the risk of having lower back problems in the future. For this purpose, a weightlifting competition more specifically "ergonomic weightlifting" in other words while you are lifting as much weight as possible you are considering your lower back area and lower back spinal forces during lifting tasks, are designed and performed. JACK software is used to create a human model that lifts weights. We followed the National Institute for Occupational Safety and Health (NIOSH), guidelines to prevent the lower back injuries that can occur while ergonomic weightlifting competition. This paper gives the detailed description of the ergonomic weightlifting competition and results of it.

Keywords
Ergonomics Task Design, Digital Human Modeling, Lifting, Lower Back Analysis, Simulation

Introduction
Digital human models (DHMs) are computer generated representations of human used in computer-aided design or similar programs. DHMs are increasingly being used by ergonomists, industrial engineers, and other engineers to design both product/equipment and work environments to meet the needs of human operators. Using a DHM, design engineers can position and manipulate operators of varying anthropometry within the simulated work environment. A variety of different analyses such as work posture, lower back, fatigue, metabolic energy expenditure and others can be performed by using DHM software packages (Bush et al., 2012). JACK, developed by Siemens Corporation (Siemens PLM Software Inc., 2008) is a DHM software package capable of simulating human involved in any number of tasks and performing ergonomic analysis. JACK is a human modeling and simulation tool. It provides some design tools for performing ergonomic analysis of virtual products and work environments. JACK enables one to improve the ergonomics of product designs and to refine industrial tasks. Using JACK one can analyze human performance while performing some tasks such as lifting, lowering, carrying etc.

Lower back injuries increase significantly when lifted objects are heavy, bulky, lifted from the floor, lifted frequently and lifted asymmetrically (by one hand or with the torso twisted). The National Institute for Occupational Safety and Health (NIOSH), US federal agency that researches and makes recommendations to prevent lifting related worker injury and illness, developed its lifting guidelines. Using the NIOSH guidelines on JACK software, we analyzed lifting, more specifically weightlifting tasks and tried to use best lifting technique to lift maximum weight by considering lower back area especially L4 and L5 area within the recommended compression limit on the L4-L5 disk. In this paper, effects of lifting tasks with lifting various weight objects were studied and analyzed by using JACK software. To study lifting tasks with DHMs, a weightlifting competition is designed for groups of students. Each group is asked to set up an environment for the weightlifting task and positions for the competition. The competition had five trails to lift the maximum weight without exceeding the lower back analysis compression limit. After five trials, the team with the maximum weight is the winner of the competition.

Background
The National Institute of Occupational Safety and Health (NIOSH) have established lifting guidelines to help to industrial workers or any individual to carry out lifting tasks and to minimize the effects and dangers on the body, specifically lower back of the individual. Some of these guidelines are to keep the object to be lifted close to the

body, bend the knees when lifting, and carry the objects using handles if possible (Konz and Johnson, 2008; Lehto and Landry, 2013). We tried to follow the NOISH guidelines to prevent the lower back injuries that can occur while lifting. We focused specially to lifting task when have a heavy load and the impact of the lifting task on the lower back spine may result a lot of injuries.

The lower back spine, the lumbar spine, consists of 5 vertebras labeled from L1 to L5. The L4 and L5 are the two lowest vertebrae in the lumbar spine, and together cushioned with the lumbar disc, attached with nerves, joints, and tissues as illustrated in Figure 1. The L4 and L5 vertebras support the upper body and allow motion in multiple directions. It is located above the sacrum and it has an aligned inward curve and has large muscles for support of the body movement. It allows the back to twist, and extend backward or forward. It carries the most weight, which makes it vulnerable to many injuries.

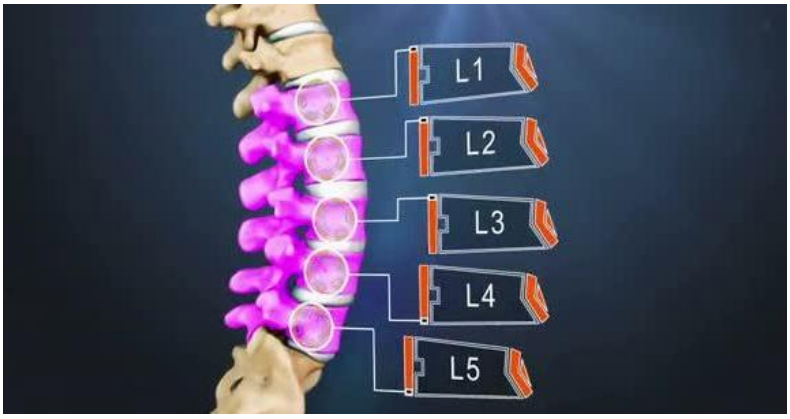

Figure 1. Vertebras of the lumbar spine (DeWitt, 2013)

The main causes of pain and injuries in the L4 and L5 area can be due to the heavy weight someone regularly carries, or the wrong way someone lifts or obesity where the body's weight acts as a force on the lumbar area, also it can be due to abnormal body motions. However, those causes can have the following effects on that area. The L4-L5 disc, in between the L4 and L5 vertebrae, can herniate. In addition, the L4 vertebra can slip forward over the L5 vertebra, impinging the nerve root causing lower back pain. Finally, the back of the L4-L5 segment has a nerve that passes through it, from inside the spinal canal down through the back of each leg. This nerve is called the L4 nerve root. If any in inflammatory proteins from inside the disc herniate and come in contact with this nerve, or if anything presses against it, pain can travel down the nerve. Here are some of the most common diseases caused by the overweight lifted by human (DeWitt, 2013 and Ullrich, 2007):

- *L4-L5 disc herniation:* It is caused by the amount of weight these segments carry. When the disc herniates, the inner portion leaks out and touches the nearby L4 nerve root, causing pain to radiate in the lower back and/or down the leg.
- *L4-L5 degenerative disc disease:* If the L4-L5 disc degenerates, it can become painful and cause lower back pain.
- *L4-L5 spondylolisthesis:* Weakness in the bones, joints, and ligaments of the spine can lead to the L4 vertebra slipping forward over the L5 vertebra impinging the nerve root and leading to leg pain and other symptoms.

For the lower back problems, we focused on to analyze the forces at the L4-L5 disc that occurs during lifting. For this analysis JACK has a low-back spinal force analysis tool in the JACK Task Analysis Toolkit (TAT) (Siemens PLM Software Inc., 2008) that evaluates the spinal forces (compression, AP shear, and lateral shear) acting on a virtual human's lower back under any posture and loading condition. Lower Back Analysis (LBA) uses a complex biomechanical lower back model to evaluate the spinal forces that act on the lower back under an unlimited number of posture and loading conditions. LBA is a tool that allows the strengths to be evaluated on the digital human models' (DHMs) spine, according to each posture assumed by the DHM and any lifting tasks. This tool evaluates the actions linked to the lifting tasks imposed on the DHM according to the NIOSH standards in real time. The LBA tool offers information related to the compression and shear strengths on the L4-L5 lumbar disk, together with the reaction-moments in the axial, sagittal and lateral plane on the L4-L5 disk and the activity level of the trunk muscles

to balance the spine moments. Herrin at al. (1986) indicated that back compression is a good predictor of lower back and other overexertion injuries. In particular, we use the compression, the value expressed in Newton, on the L4-L5 disk that is illustrated in Figure 2.

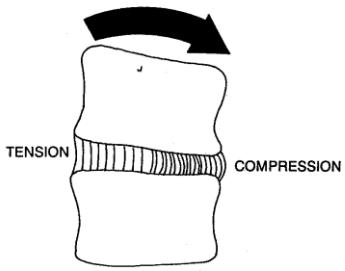

Figure 2. Compression and tension on the disk between vertebras of the lumbar spine

To compare compression values under different weights, a weightlifting competition more specifically ergonomic weightlifting, while you are lifting as much weight as possible, you are considering your lower back area and lower back spinal forces during lifting tasks, are designed and performed. Although weightlifting is a common sport, it can be very dangerous and can cause many injuries if not preformed carefully. JACK software is used to create a human model that lifts weights. We are trying to follow the NOISH guidelines to prevent the lower back injuries that can occur during weightlifting action.

Literature Review

An evaluation and comparison of the commercially available software tools in ergonomics and biomechanics research are performed by Bush et al. (2012). A comparative study of Digital Human Modelling simulation results and their outcomes in manual assembly lines for automobile manufacturing is reported by Lamkull et al. (2009). One of contemporary approaches in ergonomic analysis is the virtual environments. The application of virtual environment has been used widely to support the ergonomics evaluation, including researches conducted by Caputo et al. (2006) and Muslim et al. (2011). The detailed information about lifting tasks and NIOSH lifting guidelines can be found many ergonomics textbooks (Konz and Johnson, 2008; Lehto and Landry, 2013).

Methodology

Weightlifters lift heavy weight bars and the weights of these bars are adjustable by adding or subtracting more bars. Weightlifters practice several techniques that allow them to lift heavy weights. The most popular techniques that the weightlifters follow are snatch and clean and jerk. JACK software is used to simulate weightlifting tasks. The methodology of applying the simulation of weightlifting tasks can be done in five main steps by using JACK.

1. *Build the model for weightlifting task:* In the beginning we create a simple environment which consists of the weightlifter and the object to be lifted. The weightlifter is a default male with standard anthropometric measurements without changing any of his properties, and the object is a lifting bar. Since the weightlifting bar is not available in JACK software, we first drew half of the bar using Auto CAD then download it in Jack, copied another half and then merged them together. The environment is illustrated in Figure 3.

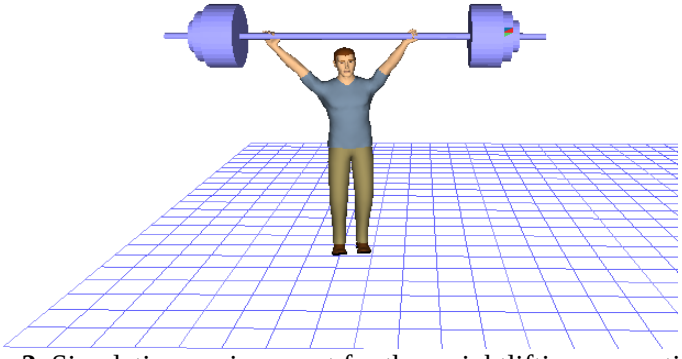

Figure 3. Simulation environment for the weightlifting competition

2. *Create simulation for weightlifting task:* We created a simulation task by choosing "Open Task Simulation Builder" from the tools, then a new window would open where there exist human options of: Put, Get, and Position and Pose, that divide the task in the following simple motions.
    - *Put:* To put the object to the desired location.
    - *Get:* To go to the object and grasp it.
    - *Position:* To adjust the position of the model and the object.
    - *Pose:* to change the pose of the model.

    The steps to do the lifting the bar was designed as follows:
    - Get the bar – we adjust DHMs hands to hold the bar
    - Put bar – DHM will lift the bar up to his waist height
    - Get the bar – adjust DHMs hands to hold the bar after the new posture
    - Put bar –DHM will lift the bar up (above his head)
    - Get bar – adjust DHM's hands to hold the bar after the new posture

3. *Perform lower back analysis for weightlifting task:* After the simulation of the lifting task had been done, an analysis of lower back is performed. The JACK software contains a built-in Lower Back Analysis (LBA) for the lower back L4-L5 disk. It shows the level of pressure on the lower back and the stress level has 3 stages which are green, yellow and red. The green area which is below 3400N stress on the lower back and, this is the safe area. The yellow area which is 6400N stress on the lower back and, this area indicate that the level of stress is high and that this may increase the risk of having an injury. The red area which is above 6400N stress on the lower back indicates that the athlete damaged his lower back because the level of stress was very high that can be seen at the see Figure 4.

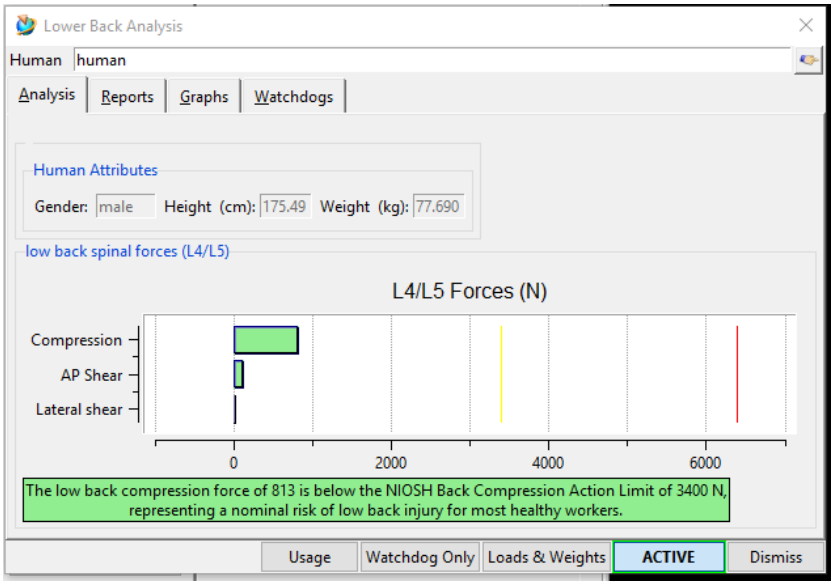

Figure 4: JACK's Lower Back Analysis window

4. *Get results:* In order to get results, we generated a "Report" by filling all important data of the "Report Header", the choosing L4 and L5 from "report data". After that we chose "Reports" option again to show the recommendations of the analysis of the best performance for the current task.
5. *Competition:* After completion of the first simulation, compression values from LBA is obtained. Based on analysis obtained, we updated the weight and repeated the simulation. The ones who are in the green or yellow area or safe zone recommended to increase their weight, the ones who are in the red area or danger zone recommended to decrease their weight. We ran the model and made different trials with different weights until we recorded the ultimate (maximum) weight that could be lifted by the operator. Finally, we obtained the maximum weight for the weightlifting the load (lifting bar) by the worker without harming the lower back. Competition is ended after five simulation run for each group.

Results

After designing the weightlifting simulation with the DHM and understanding the lifting techniques by each group, an ergonomic weightlifting competition is performed with the participation of eight groups with the total of twenty-five students. All simulation models are used the default parameters for the DHM. During the competition, each group decided their starting weight. Then, their compression force values are checked from LBA analysis. 3400N is the NIOSH Back Compression Action Limit and represents a load where there is increased risk of lower back injury for some workers. 6400N is the NIOSH Back Compression Maximum Limit representing a load where there is an increased risk of lower back injury for most workers. Their simulation models are assessed differently by the supervisor. The results of the competition is given in the following Table 1.

Table 1. Ergonomic weightlifting competition results for all participant groups.

Group name		1st Trial	2nd Trial	3rd Trial	4th Trial	5th Trial	simulation assesment	Max weight
G1	Weight	11 kg	21 kg	31 Kg	41 kg	51.7 kg	Good	51.7
	LBA-Compression	2704 N	3678 N	4565 N	5448 N	6395 N		
G2-A	Weight	40 kg	44 kg	48 kg	53 kg	58.5 kg	Fair	58.5
	LBA-Compression	4780 N	5130 N	5478 N	5918 N	6398 N		
G2-B	Weight	38 kg	41 kg	44 kg	47 kg	52.5 kg	Fair	52.5
	LBA-Compression	4972 N	5232 N	5492 N	5770 N	6357 N		
G3-A	Weight	50 kg	60	71 kg	71.5 kg	×	Excellent	71.5
	LBA-Compression	4937 N	5568 N	6262 N	6293 N	×		
G3-B	Weight	62.5 kg	62.7 kg×	62.6 kg	62.68 kg	×	very good	62.68
	LBA-Compression	6381 N	×	6393 N	6399 N	×		
G4	Weight	58 kg					good	58
	LBA-Compression	6324 N						
G5	Weight	50 kg	55 kg	61 kg	62 kg	61.7 kg	very good	61.7
	LBA-Compression	5472 N	5868 N	6336 N	×	6397 N		
G6	Weight	10 kg	15 kg	20 kg	24.5 kg	26.8 kg	good	26.8
	LBA-Compression	3803 N	4591 N	5281 N	6014 N	6385 N		

From Table 1, one can state that we have a clear winner group named as G3-A. As expected, the more weight applied to the lower back, the higher the compressive force will be. The results yielded from the activity were fairly interesting; because of changing simple aspects such as bending the knees when lifting and getting a better grip of the object, lifting objects became less susceptible injury.

Conclusion

In this paper JACK software is used to simulate lifting task with various weights in a competition environment. We studied and analyzed the lower back L4 and L5 are for weightlifting tasks. L4 and L5 area are the last two intervertebral segments in the lumbar spine. The main objective of the competition was to lift the maximum weight possible without the force compression force in L4-L5 disk exceed the NIOSH limits as this problem creates hazards and increases lower back pain .to overcomes this problem, we made analysis using JACK software to find out the best solution. By using JACK software, we tested DHMs for weightlifting by performing different body positions and by manipulating the weight lifted to reach the highest weight that the athlete can lift, without causing injury to the lower back area. Also, the results that we got from the analysis to the safety and health of the workers can be linked in different workplaces that frequently and continuously every day lift heavy objects throughout the year which results in extreme lower back problems and pains.

Acknowledgements

This “weightlifting competitions by using JACK” is designed and performed during fall semesters of 2016 as a part of an academic activity for the junior level Industrial Engineering courses. There were twenty-five students as eight

groups for this competition. Winner group and their report is used as basis for this paper. Overall competition results are also given in this paper. We would like to extend our gratitude to all participants for this competition.

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Biography

Ali Al Ramadhan, is an industrial engineering senior student. Moreover, his senior project is applying six sigma to improve a call center.

Abdulrahman Ahmad, is an industrial engineering senior student 2017. Also, his senior project is applying six sigma in order to improve a call center.

Saoud Al Otaibi, is an industrial engineering senior student and his senior project is applying six sigma to improve a call center.

Suat Kasap has degrees in electrical-electronics engineering and industrial engineering. He received his Ph.D. in Industrial Engineering from the University of Oklahoma. His research interests are in human factors and ergonomics, occupational safety and health, work and process analysis, technology and innovation management, multi-criteria decision making, financial engineering, data mining, and modeling, analysis, and optimization of complex engineering problems. He has published in Journal of Global Optimization, Simulation, International Journal of Applied Logistics, Topics in Health Information Management, Journal of History Culture and Art Research. He also authored five book chapters in Green Finance and Sustainability: Environmentally – Aware Business Models and Technologies, Development and Implementation of RFID Technology, Handbook of Applied Optimization, Encyclopedia of Optimization, Volume IV, Handbook of Combinatorial Optimization. He worked in four different Industrial Engineering Departments of the American University of Middle East, University of Turkish Aeronautics Association, Hacettepe University, and Çankaya University as an assistant professor. He has taught courses on Work Analysis and Design, Ergonomic Work Analysis, Cognitive Ergonomics Work Analysis, Technology and Innovation Management, Management of Information Systems, Introduction to Optimization and Modeling, Deterministic Models of Operation Research, Project Management, Multi-criteria Decision Making.