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Ergonomic Analysis of Work-Related Musculoskeletal Disorders on Warehouse Workers Using Digital Human Modeling

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Abstract **- Warehouses are one of the workplaces that involve manual material handling tasks that can lead to different impacts on human bodies such as causing work-related Musculoskeletal Disorders (WMSDs). WMSDs are conditions that affect muscles, joints, tendons, nerves, and ligaments. Moreover, WMSDs can be developed and be harsher if the issue is not solved promptly or proactively. Many disorders are considered WMSDs such as tennis elbow, plantar fasciitis, gout, rotator cuff, tendonitis, etc. This paper is a Digital Human Modeling (DHM) study for several warehouses including products-COOP, a refrigerator & water cooler factory, and a global logistics shipping company in the state of Kuwait to overcome workplace WMSDs. Nordic Musculoskeletal Questionnaire (NMQ) was used to understand the physical health of the warehouse workers. JACK software was utilized to investigate the workers' postures to determine the main problem to avoid and correct.**

Index Terms **- Digital Human Modeling, Musculoskeletal Disorders, Simulation, Warehouse, Ergonomics.**

INTRODUCTION

Warehouses are generally used for storing product packing and preparing before distribution, which is usually used by manufacturers, wholesalers. Working in warehouses is a heavy work that requires certain task that may lead to injuries. There are many types of hazard that workers could be exposed to while working at warehouses including ergonomic hazards. Ergonomic hazards are physical factors in the environment that may cause muscular injuries in warehouses, it is important to control all the ergonomic hazards and challenges to ensure the efficiency of the performance and the progress of the business. These challenges can pose a danger to the health and safety of workers. The ergonomic challenges of the work environment can lead to work related Musculoskeletal Disorders (WMSDs). These disorders may not appear immediately, but they affect the worker's body and health in the long term.

Implementing ergonomic solutions can make employees more comfortable and increase the productivity of the systems they are used in. In addition, ergonomics is defined as having jobs and tasks that suit the worker rather than forcing workers to finish the job. Working in a not proper posture and sticking with awkward body movements while lifting heavy weights or working in a not healthy body position can lead to many problems and put the body under stress which causes many WMSDs. Daily tasks of workers such as stand, bending, lifting, reaching, pushing, and pulling may cause these disorders. The aim of this paper is to perform ergonomic analysis of WMSDs on warehouse workers in the State of Kuwait using digital human modeling (DHM). The main objective of the paper is to seek to overcome the ergonomic of work environment to reduce the associated WMSD, resulting in a comfortable work environment and a better society. For this purpose, Nordic Musculoskeletal Questionnaire (NMQ) is adapted and used to obtain workers' WMSDs-related data. Then, the data extracted from the NMQ to identify problematic areas for warehouse workers are analyzed. After that, the tasks of workers from warehouses that affect the problematic areas the most are simulated by using Digital Human Modeling (DHM) software, JACK, and analyzed the simulation results by using the task analysis toolkit in the JACK.

BACKGROUND

The warehouse sector is a labor-intensive work that gives employees specific responsibilities to carry out. To ensure effective performance and business development, it is important to manage all ergonomic issues in warehouses. The activities of workers in warehouses include lifting, moving, picking, placing, packing, and other activities of intensity that affect their bodies in the long run [1]. Despite the use of tools and devices that reduce the workload and the physical pressure of workers, human intervention is still essential in these operations.

Warehouse operations are divided into 5 operations, which are: receiving, storing, picking up, packing, and shipping. Warehouse work involves performing certain activities such as lifting and moving things frequently. Despite their simplicity and ease, these activities are known to involve repetitive tasks and heavy lifting activities. The workers who are responsible for performing such activities make a lot of complaints about WMSDs that include pain and fatigue especially the lower back of the body. These symptoms of pain and fatigue result later in extreme injuries [2]. Awkward postures refer to bodily positions that depart from the neutral stance while carrying out a task. When our bodies are in awkward postures, our muscles function less effectively, resulting in increased effort and energy expenditure to accomplish the activity at hand. Awkward postures increase the chance of having injuries which may stress joint components and reduce blood flow. Moreover, awkward postures can increase the chance of having WMSDs over time [3]. Awkward postures are dangerous because they cause WMSDs [4]. WMSDs cause a wide range of symptoms such as stiffness, pain, swelling, weakness, numbness, and tingling. In warehouses, workers often engage in different motions and physical labor which puts the body in a higher chance of having WMSDs. The common WMSDs in warehouses:

Back disorders: They are caused by lifting heavy weights or performing rigorous repetitive bending and twisting movements that lead to several issues such as Herniated disc, Sciatica, Scoliosis, and Spondylolisthesis.

Shoulder disorders: They are caused by overhead reaching or repetitive lifting that led to several issues such as Rotator cuff injury, Shoulder impingement syndrome, Shoulder dislocation, Bursitis, and Frozen shoulder.

Neck disorders: They are caused by prolonged periods of looking up like when loading or unloading overhead shelving and these awkward movements causes many issues such as Neck herniated disc, Cervical strain/sprain, Cervical spondylosis, Whiplash,

Knee disorders: They are caused by kneeling or prolonged standing, plus repetitive bending and twisting movements that result in different problems such as Meniscus tears, Anterior cruciate ligament (ACL) injuries, Osteoarthritis, Knee bursitis, etc.

Tendinitis: It is the inflammation that happens on the tendons of the workers caused by repetitive motions resulting in severe disorders such as Tennis elbow, golfer elbow, Rotator cuff tendinitis, etc.

There are many steps that are required to avoid WMSDs caused by awkward postures. First, reducing stress over bodies by making proper lifting techniques. Second, taking rests when it is needed. Third, exercising the muscles is important because it will make the muscles strong which helps in avoiding injuries.

Experts have built a range of instruments and questionnaires to measure subjective WMSD concerns based on a variety of common complaints.

The Nordic Musculoskeletal Questionnaire (NMQ) is a measuring instrument that is often used to assess musculoskeletal conditions all over the world. The Nordic Council of Ministers supported the creation of the NMQ, which resulted in a simple, standard questionnaire [5]. The questionnaire comprises well-organized and compelling multiple-choice questions, and can be utilized either as a self-administered survey or as an interview, as shown in Figure 1. NMQ enables the assessment of musculoskeletal issues across many anatomical locations in epidemiological investigations with many participants. The NMQ was designed to be user-friendly and provides a standardized method for assessing the occurrence and consequences of musculoskeletal disorders [6]. The NMQ is consisted of two major parts explained as follows: First part of NMQ evaluates the symptoms WMSDs in nine anatomical regions of the body: upper back, lower back, neck, elbows, shoulders, wrists/hands, hips/thighs, knees, and ankles/feet. Second part of NMQ evaluates the effect of WMSDs on work-related activities, for instance, job tasks, use of different equipment, and work pace. An extensive review of applications of NMQ are given in [7].

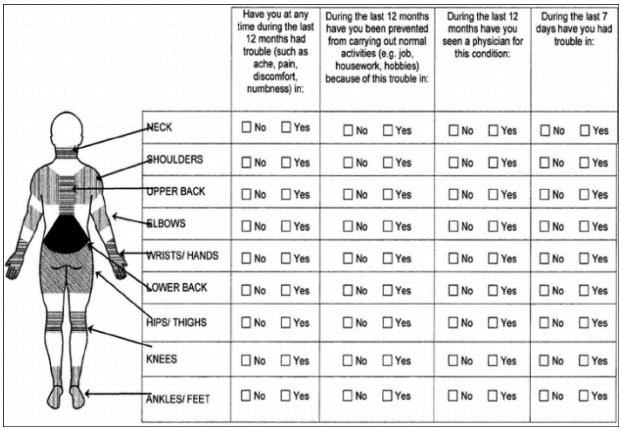

FIGURE 1 STANDARDIZED NORDIC MUSCULOSKELETAL QUESTIONNAIRE

Digital human modelling (DHM) is a method used to simulate human interaction with a product or workplace in a virtual environment. DHM provides crucial analytic tools for analyzing, graphically displaying, integrating, and mathematically modeling of the human body and needed anthropometric information. Designers prefer the DHM technique for the ergonomic redesign of products and systems. The DHM software is being combined with ergonomic analysis tools and human characteristics. The suggested framework by the researchers utilizes DHM to combine performance measurements of both humans and machines in order to provide interventions, resulting in a sustainable system that is consistent with human capabilities [8]. Manikins in three dimensions are also referred to as digital human models. Before building a physical prototype, designers can see how well a design works using these computer representations of people.

DHM computer programs let users import their 3D Computer-Aided Design (CAD) models into a virtual environment because they are based on the same types of technologies as CAD tools. Then, for design analysis, DHMs of various sizes can be added to this environment together with the model. Enhanced workplaces or goods lessen their reliance on others and promote active participation in work, communication, and social life. The importance of DHM can be attributed to how well it supports training and procedures. With the use of digital human, experts from a variety of industries can run simulations specific to their industry to see potential outcomes that could be applied to real- world situations and assess their efficacy. DHM demonstrates how important it is for efficient digital support. With the aid of digital humans, the function of digital assistance shifts from assisting users by delivering answers and carrying out simple tasks to improving verbal communication and efficiency with a more realistic experience. Importantly, digital human advances synthetic data generation, making it simpler for businesses to respond to these changes. Disruptive technology is an unavoidable event. Contemporary product development is undoubtedly shifting towards a benchmark that prioritizes the effective utilization of computational modelling and simulation technologies at the beginning of the design phase.

DHM software such as JACK, CATIA, DELMIA, SAMMIE, SANTOS, and RAMSIS is used to enhance the workers daily tasks and make their work more effective because the software increases the DHMs' anthropometric and biomechanics database integration, Creating simulation models for a wide range of manual jobs that predict the coordinated body segment motions needed, Improve biomechanics models for musculoskeletal stress analysis and prediction in manual job simulations and Create reliable and universal techniques to enhance the interface between workstation CAD programs and current DHMs [9]. A significant goal for most DHM developers has been to accurately forecast realistic human movements across various occupations. In order to establish the most effective approach for reaching this goal, advanced motion optimization algorithms, control system models, and functional regression approaches are employed, along with extensive motion databases. The advancement of predicting realistic movement features of healthy individuals has made great progress. The movements associated with tasks that need individuals to stabilize themselves, access tight spaces, or exert extraordinary amounts of force, however, lack clear characterization. More specifically, compensatory movements frequently used by those with back or other musculoskeletal problems, or by those exerting themselves to the limit physically, are poorly predicted [10, 11, 12]. The software for ergonomic simulations has analysis tools that can help identify problem areas early on.

The key features to help production engineers see the wider picture and better comprehend the opportunities that exist within DHM for doing ergonomic studies throughout the design phase such as RULA, NIOSH, lower back analysis and comfort analysis, this tool enables users to create brief animations that demonstrate the human model performing the required tasks, allowing for the identification of potential hazards [13].

The JACK software is a versatile tool that allows users to create models and simulations of human behavior. By utilizing this software, users can improve the ergonomics of product designs and optimize industrial processes. JACK provides resources for conducting ergonomic assessments of virtual products and virtual workspaces, in addition to supplementary toolkits for ergonomic analysis. JACK allows for the adjustment of human model sizes to align with worker demographics and enables the assessment of designs based on several parameters, including user comfort, reachability, line of sight, energy consumption, exhaustion, and other important human factors. JACK software in this project is utilized for purposes of analysis and research. Via JACK platform analysis, variation indices of evaluation are put across. If there is a failure, an optimization of the environment is done. Then the simulation verification is done accordingly to ensure the safety of the simulated environment [14].

It is a must to consider ergonomics in the workspace because there are many studies showing that employees would perform better and higher quality of work as they are working in a healthy and safe workspace’s claim rate seemed to have more jobs with a high biomechanical exposure than those with a low WMSD claim rate symptoms may be reduced through ergonomic arrangement companies with a high [15]. Their finding provides useful information for developing novel strategies aimed at enhancing workplace interventions that are essential to improve the occupational risk assessment and management procedure and consequently put into place the resulting health surveillance systems, also helping identify gaps in current risk assessment strategies.

Maula et al. [16] did a risk analysis study of MDS on logistics warehouse workers to examine how the human body can be affected by receiving static loads or working on awkward posture in the long term. In their study, Rahman and Zuhaidi [17] investigated the detrimental effects of WMSDs symptoms and ergonomic risks on grocery retail workers in the industry. Basahel [3] has investigated work-related WMSDs in warehouses in Saudi Arabia. Arminas and Nurwahidah [18] have investigated the working posture analysis on the WMSDs of workers in a factory that uses raw sugars to produce refined sugar. Palikhe et al. [19] conducted an examination of musculoskeletal issues and muscular strains caused by construction workers' uncomfortable body positions using simulation.

METHODOLOGY

The methodology of the study consists of several steps explained as follows:

- *Investigation of WMSD concerns:* The following actions should be taken to identify WMSD concerns of warehouse workers.
  1. Visit various warehouses with lifting and carrying dominated tasks to interview with warehouse workers.
  2. Record workers' movements while performing various tasks to study their awkward movements and postures
  3. Perform a NMQ based interview with the workers to localize WMSD issues on the workers' body.
- *Development of virtual environment and Digital Human Models:* After visiting warehouses and recording awkward movements and postures while performing various tasks should be identified as simulation tasks and they are simulated by using DHM software, namely JACK software Digital Human Modeling and Simulation Tool, by the following actions:
  1. Build a virtual warehouse environment.
  2. Create digital human models by using anthropometric databases to represent warehouse worker.
- *DHM simulation and ergonomic analysis:* Each posture should be analyzed using different JACK toolkits such as Low Back Analysis (LBA), Rapid Upper Limb Assessment (RULA), Ovako Working Posture Analysis (OWAS). The LBA tool provides information on the compression and shear forces exerted on the L4/L5 vertebral joint at lower back area. The RULA tool facilitates the assessment of workers' exposure to the risk of upper limb injury and assigns a score to the examined task, indicating the level of intervention necessary to mitigate the risk of an upper limb injury. The OWAS tool offers a straightforward approach to promptly assess the ergonomic suitability of working postures and ascertain the necessity of implementing corrective actions. Then, the result of each posture should be explained in detail to know what exactly the cause of WMSDs was to consider a proper solution that overcome the main issue.

RESULTS AND DISCUSSION

Products-COOP, Refrigerator & Water Cooler Factory (RWCF) , and Global Logistics Shipping Company (GLSC) warehouses located in Kuwait are visited to interview with warehouse workers. It is realized that majority of the handling tasks are performed manually without technological advanced tools or robots.

First two of them does not have advanced equipment for lifting and carrying heavy weights, however, the last one has automated conveyers for carrying. Workers' postures while they are working are recorded to study their awkward movements and postures. Then an interview with each worker in the warehouses based on NMQ is performed. Total number off workers and the total number of interviewed workers are giving in the following Table 1. It should be noted that all of the interviewed workers were men.

TABLE 1
NUMBER OF PARTICIPANTS

Company	Number of participants	
	# of workers in company	# of workers interviewed
COOP	60	10
RWCF	14	8
GLSC	80	18
TOTAL	154	**36**

Based on the analysis of the interview results shown in Figure 2 below, it can be seen that the highest body region affected is the Lower Back with 18 complaints, then the Neck with 8 complaints, then the Shoulders with 6 complaints, and lastly Knees with 5 complaints. Note that, very few complaints are not considered for the ergonomic analysis. After finding the most problematic areas, the average time for the problem occurrence was determined. In addition to determining whether the cases needed hospitalization or not in the three warehouses. The most warehouse workers that suffered from WMSDs are products-COOP workers and the lower back is the most WMSD that received compliments.

After visiting the Products-COOP warehouse and recording the movements of the workers while they are doing their tasks, analyzed the postures while performing each task shown as follows below. Real task pictures and simulation pictures by using JACK software of these tasks are illustrated in Figure 3

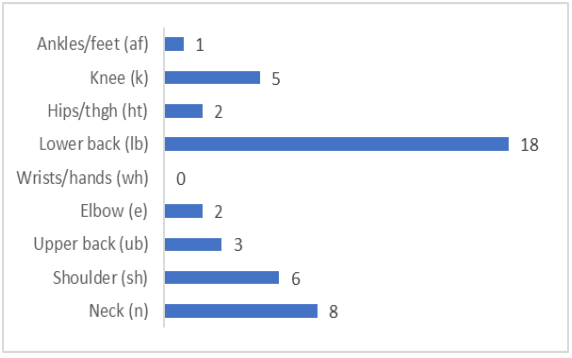

FIGURE 1 QUANTIFYING THE PREVALENCE OF WMSDS AMONG THE WORKING POPULATION

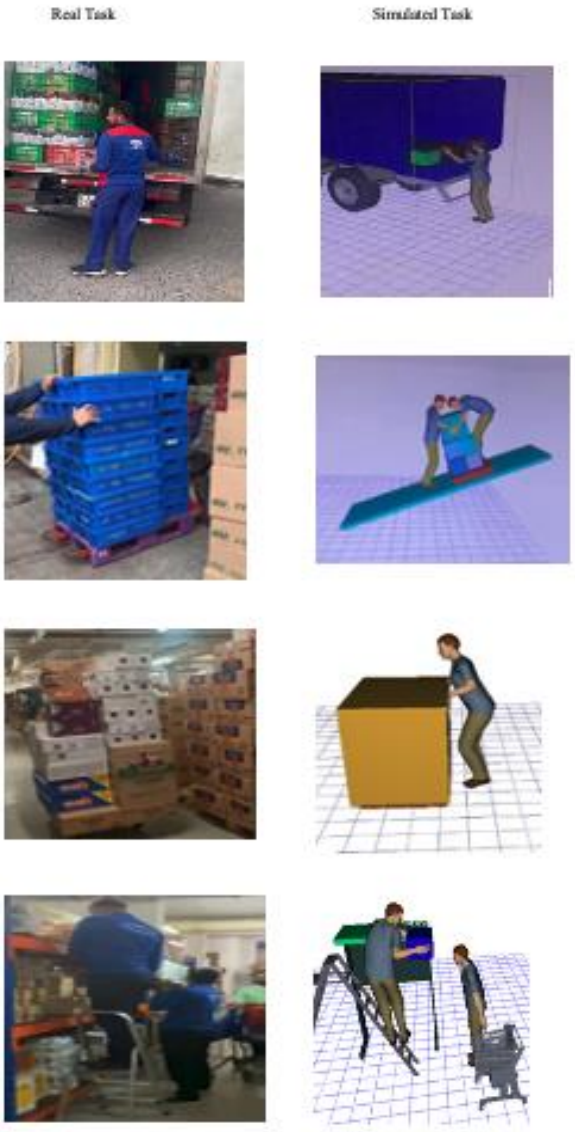

FIGURE 3 COMPARATIVE DEMONSTRATION OF ACTUAL OCCUPATIONAL TASKS VERSUS SIMULATED TASKS

Identified tasks for ergonomic analysis are as follows: unloading from a supplier truck, transferring products in the warehouse, pushing a cart, and carrying products from warehouse shelves to market shelves. These tasks are simulated by using JACK software as the real case with digital human models by using 50th percentile of the measured height and weight data, 170.5 and 74.5 respectively, of the workers.

Task 1: Unloading from a supplier truck: JACK simulation results for LBA tool indicate that the compression force and shear force are 1961 N and 766 N, respectively as illustrated in Figure 4, representing the nominal risk of the low back that most workers suffer from due to the weird bending. Furthermore, the simulation outcome of fatigue analysis advised the initiation of a reduction in the task demands placed on the right ankle joint.

It should be noted that additional reductions in effort may be necessary to prevent exhaustion in other muscle groups, as determined by fatigue analysis.

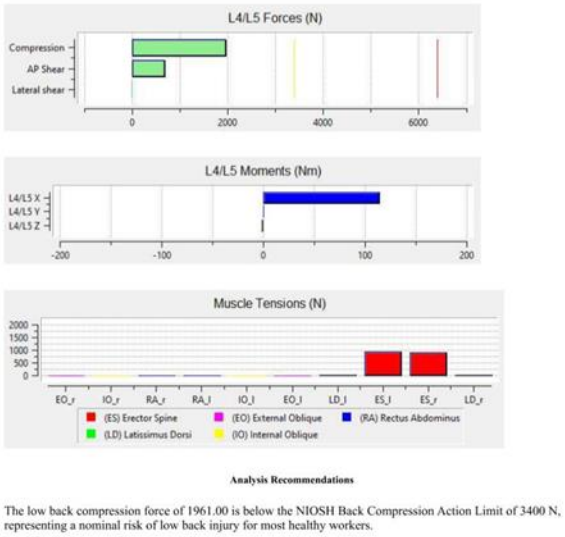

FIGURE 4 LOW BACK ANALYSIS (LBA) ANALYSIS OF TASK #1

Task 2: Transferring products in the warehouse: Based on the result of RULA analysis as shown in Figure 5, the grand score of the worker was 5 which is considered as a high ergonomic risk linked with the task. 6 band score refers to the fact that the task may cause discomfort or pain in the upper limbs of the worker if corrective measures are not taken. A grand score of 4 was achieved for the second worker and some changes must be made to the task to reduce the ergonomic risks. The lesser the RULA score, the lesser the percentage of having WMSDs associated with the task.

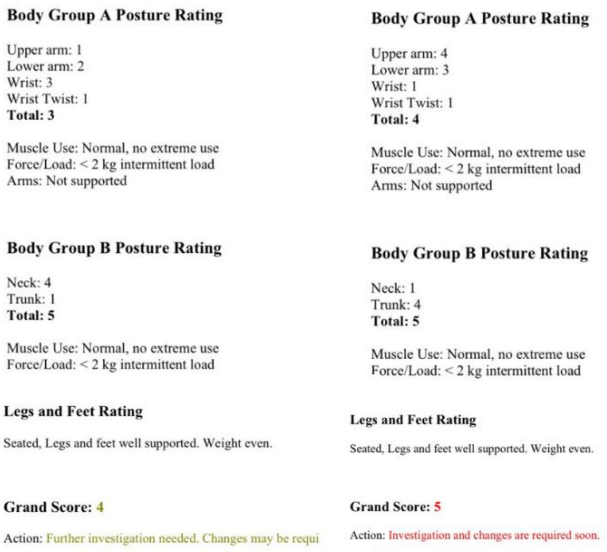

FIGURE 5 RAPID UPPER LIMB ASSESSMENT (RULA) OF TASK #2

Task 3: Carrying from warehouse shelves to market shelves: By the OWAS posture evaluation results as illustrated in Figure 6. The working position might have detrimental effects on the musculoskeletal system. Furthermore, the musculoskeletal loading associated with this position is not excessive, but it is advisable to take corrective actions. It should be noted that only the vertical force components are taken into account in the analysis. Score 2 means that corrective measures are encouraged.

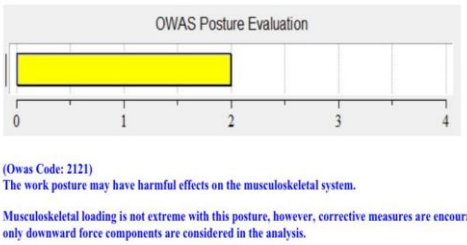

FIGURE 6 OVAKO WORKING POSTURE ANALYSIS (OWAS) OF TASK #3

Task 4: Pushing a cart: JACK simulation results for LBA tool indicate that the compression force and shear force are 4434 N and 5800 N, respectively as illustrated in Figure 7. It should be noted that, low back compression force of 4434 N is above the NIOSH back compression action limit of 3400 N. This case represents an increased risk of the lower back injury for some workers. Hence, it is recommended that this task analyzed further for ways to reduce low back forces. Furthermore, it is indicated that the AP shear outcome is higher than compression as a result of tasks involving pushing and pulling, when the exerted force is perpendicular to the back.

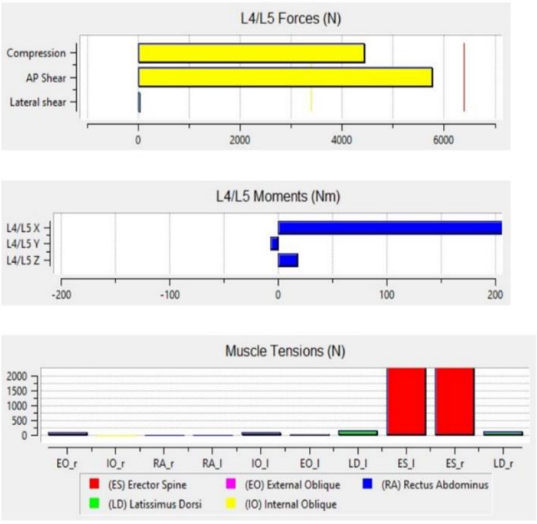

FIGURE 7 LOW BACK ANALYSIS (LBA) ANALYSIS OF TASK #4.

CONCLUSION AND FUTURE WORK

Doing a study to investigate WMSDs warehouse workers are suffering from in Kuwait is worthwhile. The main purpose of the study is to know the WMSD that the warehouse workers are suffering from to find a solution to minimize or eliminate the cause of the problem by using a DHM software called JACK software and an NMQ questionnaire. Different warehouses have visited in Kuwait including products-COOP, a refrigerator & water cooler factory, and a global logistics shipping company. Many warehouse workers that suffered from WMSDs are products-COOP's workers and the lower back is the most WMSD that received complaints. Different toolkits were used to analyze each posture. After analyzing the main causes of the WMSDs, the beneficial solutions were emphasized. Finally, the study can be extended as future work by analyzing many more awkward postures and movements to know the physical health status of their warehouse workers.

REFERENCES

[1] Lee, J. A., Chang, Y. S., & Karwowski, W. (2020). Assessment of working postures and physical loading in advanced order picking tasks: A Case study of human interaction with automated warehouse goods-to-picker systems. Work, 67, 855-866. doi:10.3233/WOR-203337

[2] Kamat, S. R., Zula, N. M., Rayme, N. S., Shamsuddin, S., & Husain, K. (2017). The ergonomics body posture on repetitive and heavy lifting activities of workers in aerospace manufacturing warehouse. In IOP Conference Series: Materials Science and Engineering. 210. IOP Publishing.

[3] Basahel, A. M. (2015). Investigation of work-related musculoskeletal disorders (MSDs) in warehouse workers in Saudi Arabia. Procedia Manufacturing, 3, 4643-4649.

[4] Keyserling, W. M., Brouwer, M., & Silverstein, B. A. (1992). A checklist for evaluating ergonomic risk factors resulting from awkward postures of the legs, trunk and neck. International Journal of Industrial Ergonomics, 9(4), 283-301.

[5] Kuorinka, I., Jonsson, B., Kilbom, A., Vinterberg, H., Biering-Sørensen, F., Andersson, G., & Jørgensen, K. (1987). Standardised Nordic questionnaires for the analysis of musculoskeletal symptoms. Applied ergonomics, 18(3), 233-237.

[6] López-Aragón, L., López-Liria, R., Callejón-Ferre, Á. J., & Gómez-Galán, M. (2017). Applications of the standardized Nordic questionnaire: a review. Sustainability, 9(9), 1514.

[7] Descatha, A., Roquelaure, Y., Chastang, J. F., Evanoff, B., Melchior, M., Mariot, C., ... & Leclerc, A. (2007). Validity of Nordic-style questionnaires in the surveillance of upper-limb work-related musculoskeletal disorders. Scandinavian journal of work, environment & health, 33(1), 58.

[8] Rajesh, R., & Srinath, R. (2016). Review of recent developments in ergonomic design and digital human models. Ind Eng Manage, 5(186), 2169-0316.

[9] Chaffin, D. B. (2008). Digital human modeling for workspace design. Reviews of human factors and ergonomics, 4(1), 41-74.

[10] Chaffin D. B., Woolley C., Dickerson C., Parkinson M. (2004). Modeling of object movement capability in the spinal cord injured population. International Journal of Industrial Ergonomics, 33, 229–236.

[11] Larivière C., Gagnon D., Loisel P. (2000). Effect of load on the coordination of the trunk for subjects with and without chronic low back pain during flexion-extension and lateral bending tasks. Clinical Biomechanics, 15, 407–416.

[12] Lindbeck L., Kjellberg K. (2001). Gender differences in lifting technique. Ergonomics, 44, 202–214.

[13] Berlin, C., & Adams, C. (2017). Production ergonomics: Designing work systems to support optimal human performance. Ubiquity press.

[14] Niu, J.W., Zhang, X. W., Zhang, X., & Ran, L. H. (2010). Investigation of ergonomics in automotive assembly line using JACK. IEEE International Conference on Industrial Engineering and Engineering Management (pp. 1381-1385,). IEEE. doi:10.1109/IEEM.20

[15] Bao, S., Howard, N., & Lin, J. H. (2020). Are work-related musculoskeletal disorders claims related to risk factors in workplaces of the manufacturing industry?. Annals of work exposures and health, 64(2), 152-164.

[16] Maula, N. Z., Suwandi, T., & Nilamsari, N. (2016). Risk analysis of Musculoskeletal Disorders (MSDs) on Logistic Distribution Workers in Warehouse of PT. X Surabaya. International Journal of Advanced Engineering, Management and Science, Vol. 2, No. 7, 239580

[17] Rahman, M. N. A., & Zuhaidi, M. F. A. (2017, August). Musculoskeletal symptoms and ergonomic hazards among material handlers in grocery retail industries. In IOP Conference Series: Materials Science and Engineering (Vol. 226, No. 1, p. 012027). IOP Publishing.

[18] Arminas & Nurwahidah, A. (2019, May). Ergonomics risk analysis of public transportation drivers (study case: public transportation drivers in Makassar City). In IOP Conference Series: Materials Science and Engineering (Vol. 505, No. 1, p. 012138). IOP Publishing.

[19] Palikhe, S., Yirong, M., Choi, B. Y., & Lee, D. E. (2020). Analysis of musculoskeletal disorders and muscle stresses on construction workers' awkward postures using simulation. Sustainability, 12(14), 5693.

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