Abstract—Musculoskeletal disorders are among the most prevalent conditions in workers performing manual material handling (MMH) activities. In this study, MMH of a dashboard was investigated in a car assembly line. Several quantitative (i.e., biomechanical models) and qualitative (e.g., NIOSH, RULA, REBA, and OWAS) assessment tools were used to evaluate the musculoskeletal injury risk of sequential lifting, carrying, and lowering of the dashboard. The lowering (installing the dashboard) task had the highest risk of injury. Two easy-to-apply interventions were proposed to successfully reduce injury risk according to most of the assessment tools.

Keywords—musculoskeletal risk assessment, low back pain, interventions, job analysis, automotive assembly plant

I. INTRODUCTION

Work-related musculoskeletal disorders (MSDs) are great challenges for automotive manufacturing industries due to exposure to various physical risk factors, especially during manual material handling (MMH) tasks, e.g., lifting, carrying, pushing, pulling, and lowering. The causal association between MMH and low back pain (LBP), which is the most common musculoskeletal disorder, has been well established [1]. It has been shown that LBP results in increased absence from work that in turn adversely affects productivity and economic costs [2].

Various ergonomic risk assessment tools are developed to evaluate the risk of musculoskeletal injuries. Qualitative ergonomic tools (e.g., the revised NIOSH equation [3]) use a set of work-related parameters such as load weight, vertical/horizontal hand load distances, and task frequency to estimate the ergonomic risk. Additionally, quantitative tools (e.g., biomechanical models [4], [5]) are capable of estimating the spinal loads, particularly in the lower back (typically L4-L5 and L5-S1) thereby predicting the ergonomic risk of various tasks [6]. Practitioners in the field of occupational biomechanics utilize these tools to design proactive ergonomics and remedial actions toward management of MSDs [7]. Several comparative evaluations have been carried out on the results of qualitative [8]–[10] and quantitative [6], [11] tools to show their relative accuracy in practical applications.

A previous study on the employees of Iran Khodro Corporation (IKCO), a well-known car manufacturing industrial group, shows that in a developing country such as Iran, LBP is a common problem in the working population [12]. Recently, the task of lifting, carrying, and lowering the car dashboard in the assembly line has shown a high prevalence of MSDs, especially LBP, in the employees of IKCO. Furthermore, few automotive manufacturing industries have published their ergonomic risk assessment techniques and intervention strategies; some examples are truck manufacturing plants [13], [14] and automotive parts distribution operations [15].

The present study aims to: 1) assess risk of musculoskeletal injuries in workers during dashboard assembly job task and 2) propose cost-effective administrative and engineering interventions to reduce the ergonomic risk factors during this task. The critical posture during which the L4-L5 or L5-S1 spine compression forces are maximal are first identified. Subsequently, various qualitative and quantitative ergonomic risk assessment tools before and after the proposed interventions were used to assess the ergonomic risk of this task at the critical posture.

II. METHODS

A. Tasks and context of study

The study was conducted in a sector of the IKCO automotive component assembly plant. The dashboard assembly workstation was selected for task assessment as the prevalence of musculoskeletal discomforts in the workers of this job was acknowledged. Job tasks in this workstation included repetitive motions, forceful exertions and awkward postures, which were grouped into three main sequential tasks: lifting, carrying and lowering the dashboard. Lifting was carried out by two workers from a knee height stand, carrying was performed by both employees within a 10-meter distance from the stand to the automotive in the assembly line, and finally, lowering the dashboard in the automotive chassis was performed alone by either of the workers from the passenger’s side (Figure 1). Moreover, the front car passenger doors had been mounted on the automotive beforehand, due to a defect in the assembly line design thus restricting the workers’ space to lower/install the dashboard. The automotive dashboard (23 kg) had a length of 140 cm and a width of 70 cm. The center of gravity was estimated to locate 55 cm from the driver’s side.
B. Data Collection

Accurate motion analysis via inertial sensors or other skin-based optical devices was not possible due to the imposed security restrictions by IKCO. Therefore, a replacement method was used to measure the subject’s posture and extract anatomical joint angles. Several photographs were taken from each worker performing their assigned task. Subsequently, a different individual imitated the real workers’ postures carefully in a proper situation and two photographs were taken from perpendicular planes, i.e. the front and side views (Figure 2). Subsequently, front and side view photographs were analyzed using Digimizer image analysis software to determine the 3D coordinates of essential body joints. Eventually, the 3D coordinates were imported to the AnyBody Modeling System, and the workers’ postures were modeled in this software. Furthermore, the anatomical angles of body segments were extracted from this model and used as input into all assessment tools.

C. Assessment Tools

Several tools were used in order to evaluate the risk of musculoskeletal injuries to workers. These tools can be classified into two main groups [16]: qualitative and quantitative tools. Several qualitative risk assessment tools were used including the revised NIOSH equation [3], Lifting Fatigue Failure Tool (LiFFT) [17], rapid upper limb assessment (RULA) [18], rapid entire body assessment (REBA) [19], Ovako Working Posture Analysing System (OWAS) [20], manual task risk assessment (ManTRA) [21], Manual Handling Assessment Charts (MAC) [22], WISHA Lifting Calculator [23], and RENAULT Ergonomic Assessment Method V3 [24]. Besides, several quantitative tools were used to directly estimate the spinal loads [11] including the AnyBody Modeling System™ (AnyBody Technology, Aalborg, Denmark) [25], University of Michigan’s 3D Static Strength Prediction Program™ (3DSSPP) [26], Regression models of Arjmand et al. [4], [5], Siemens Jack [27], Revised Hand-Calculation Back Compressive Force (HCBCF) equation [28], Linked-Segment Biomechanical Model (LSBM) [29], Simple polynomial equation of low back compression [30], and CATIA ergonomics analysis [31].

Some of the foregoing tools have their own unique classification methods to score the risk factor. In contrast, others do not provide any threshold values for their output, leaving the interpretation to the user. Consequently, to have an overview of the findings of the assessment tools altogether, the risk levels of the tools were reclassified into three levels; the safe zone, the risk zone, which requires ergonomic attention, and the danger zone that demands immediate ergonomic interventions. These risk levels are demonstrated by “1”, “2”, and “3”, respectively (Table 1).

Figure 2) The modeling and simulation process for the lowering task: a) picture from the worker performing his assigned task in the IKCO assembly line, b) the task imitated carefully by a different individual, c) 3D coordinates of essential body joints extracted from Digimizer and d) the final posture in the AnyBody Modelling System derived by the 3D coordinates.
To evaluate the risk of injury in the workstation, first, some of the quantitative tools (i.e., AnyBody Modeling System, the regression models of Arjmand et al., 3DSSPP, and Jack) were used to identify the critical posture/task in the sequence. The worker is the most vulnerable to the ergonomic risk factors during the critical task, in which the spine is subject to the highest intervertebral (L4-L5 or L5-S1) compression force. Once the critical task was detected, all the aforementioned assessment tools were used to evaluate the risk of injury in the critical task. Finally, administrative and engineering interventions were suggested to reduce the risk level of the critical task. The modified tasks (i.e., after interventions) were reassessed by implementing the same assessment tools to investigate effectiveness of the interventions.

III. RESULTS

A. Identifying the Critical Task

The maximal L4-L5 compression load as evaluated by three (out of four) quantitative tools occurred during the lowering task (critical task) (Figures 3 and 4).

Figure 3) The L4-L5 intervertebral compression load in the three main job tasks evaluated by four quantitative tools.
B. Risk Level Estimation of the Critical Task

Apart from HCBCF, other tools showed considerable injury risk on at least one body segment in the critical task. Moreover, all quantitative tools, but 3DSSPP, reported a potential chance of violating the safe zone in the lower back (Table 2).

C. Changing the Side of the Task (Intervention 1)

Workers tended to take down and mount the dashboard from the passenger’s side door. Changing this direction to the driver’s side door resulted in smaller external moments on the low back, causing significant changes in risk levels as suggested by most of the quantitative tools. In contrast, qualitative tools were not sensitive to this intervention (Table 2).

D. Lowering the Dashboard Together (Intervention 2)

All quantitative and qualitative assessment tools except LIFFT reported a safer state when lowering the dashboard was carried out by both workers; showing a safe zone status due to the more efficient distribution of workload between the workers (Table 2). Furthermore, all quantitative tools predicted that the amount of spine compression load was low enough to be considered below the danger zone (3400 N) (Figure 5). (Table 2)

Table 2) The ergonomic risk level in the critical task in different body regions, before and after implementing each intervention.

<table>
<thead>
<tr>
<th>Assessment tool</th>
<th>Body region</th>
<th>Initial risk status</th>
<th>Risk status after installing the dashboard from the driver side (intervention 1)</th>
<th>Risk status after performing the task by both workers (intervention 2)</th>
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<tr>
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<td>1</td>
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IV. DISCUSSION

We aimed to estimate the general risk of musculoskeletal injury during lifting, carrying, and lowering a car dashboard in the assembly line sector of IKCO by utilizing various qualitative/quantitative ergonomic risk assessment tools and also propose efficient administrative/engineering interventions. The lowering task was identified as the most critical task where the largest spine compression forces were predicted. The lowering task (Figure 2) had significant injury risk as identified by all tools except HCBCF that failed to recognize the elements of this complicated body posture.

The dashboard rack stands were located on the right side of the automotive due to the assembly line design; therefore, the workers had to put down the dashboard from the passenger’s side of the automotive (Figure 6). Based on the reports of IKCO’s technical supervisors, the dashboard’s center of mass is located further towards the driver’s position. This difference between the center of mass and geometrical center results in asymmetrical workload, and consequently, the stretched-out arm has to support the heavier side of the dashboard (the driver’s side), producing larger moments at the worker’s lower back. According to our findings, changing the side of the task provided smaller moments at the intervertebral disc as the center of mass was closer to the worker’s body. As a result, the ergonomic risk levels in the modified task (after intervention 1) were reduced in most of the quantitative tools. In contrast, qualitative tools showed changes only in few cases (Table 2). Generally, our results indicated that the modified task was safer than the initially designed task (only RULA, REBA, and V3 tools predicted a danger zone after the intervention). Furthermore, the interesting differences between results of the qualitative and quantitative tools demonstrated the importance of the moments exerted to the body in musculoskeletal models as compared to multiplier sets used in qualitative tools.
Note that the only change caused by this intervention (changing working side) is the fact that moments are reduced at the lower back that is one of the most important factors in ergonomic analysis. Moreover, implementing this engineering intervention to the car assembly line will decrease the ergonomic risk at relatively low cost and minimum structural changes by transferring the rack stand of the dashboard to the opposite side of the workstation to make it closer to the driver’s side of the automotive.

According to IKCO’s supervisors, the assembly line will be modified immediately in a way that the doors would not be mounted on the automotive before the large parts like the dashboard and seats are mounted. As a result, workers can hold the dashboard from both sides and lower it as a pair work. Therefore, risk assessment was carried out for the pair work lowering task to assure the critical (lowering) task is safe enough.

The amount of the workload is another effective parameter in the risk of injury assessment as it directly affects the intervertebral joint compression force. The individual lowering task was found as the critical task because of the high workload along with the awkward posture. As the car doors were mounted beforehand, the workers’ space was restricted thus forcing the workers to take awkward postures while also lowering the dashboard alone and consequently doubling the workload. Removing this fault from the assembly line design allows the workers to perform this task as a pair work, thus providing a more efficient load distribution and eliminating the awkward posture. Our results (all tools except RULA, REBA, and LIFT) showed a safe zone status for the pair work task (Table 2). While changing the assembly line structure can be costly and time-consuming, the modified task will be completely safe.

Besides the engineering interventions, easily attainable administrative interventions were suggested to the workstation supervisors in order to reduce the risk of musculoskeletal disorders. Since the critical task used to be carried out by one single worker, a change of plan was proposed, so each worker would swap position in the task after each complete cycle. This intervention can reduce the workers’ fatigue caused by load.

We included several tools (9 qualitative and 8 quantitative tools) while briefly comparing their findings for the job task under consideration. A throughout comparison needs detailed data of many tasks performed in several sections of various industries and workplaces. However, this is a first step towards a comprehensive comparison study between ergonomic assessment tools to demonstrate their relative accuracy in practical applications.

Our major limitation of this study, as also mentioned in the methods section, was in acquiring accurate motion data in the workstation by inertial sensors [32] or marker-based motion capture systems [16]. An extensive modeling approach was, however, designed and conducted to prevent a great loss of accuracy.

CONCLUSION

In this study, the dashboard assembly task in the IKCO automotive assembly plant was assessed using several quantitative and qualitative risk assessment tools. Results indicated that the critical task in the assembly sequence was the lowering task, in which the worker was exposed to a high risk of musculoskeletal injury. Therefore, feasible engineering interventions were proposed that could reduce the exerted load on the worker's low back. After modifying the assembly line, the lowering task can be carried out as a pair work, resulting in a significant reduction in the risk of injury.

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