ORIGINAL ARTICLE

EVALUATION OF MANUAL LIFTING AND LOWERING ACTIVITIES USING REVISED NIOSH LIFTING EQUATION: A CASE STUDY AMONG AUTOMOTIVE ASSEMBLY WORKERS

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ABSTRACT

Workers in the automotive industry are exposed to various manual material handling activities that lead to Work-related Musculoskeletal Disorders (WRMSDs). Lifting and lowering loads are the main activities in the development of low back pain among the workers. A cross-sectional study was conducted to calculate Recommended Weight Limit (RWL) and Lifting Index (LI) for the selected lifting and lowering activities and to determine the prevalence of WRMSDs symptom among the workers. 120 male subjects were selected through purposive sampling. Standard Nordic Questionnaire (SNQ) was applied to identify WRMSDs. Meanwhile, NIOSH Revised Lifting Equation (NRLE) was used to evaluate job activities. Recommended Weight Limit (RWL) and Lifting Index (LI) for lifting and lowering tire were 11.78 kg (RWL origin) and 13.32 kg (RWL destination); 0.67 (LI origin) and 0.60 (LI destination) respectively. Meanwhile, RWL and LI for lifting front car bumper were 4.13 kg (RWL origin) and 3.72 kg (RWL destination); 1.40 (LI origin) and 1.08 (LI destination) respectively. The highest musculoskeletal disorder prevalence was lower back (39%), followed by shoulder (14%), upper back (11%), elbow (11%), neck (7%), wrist/hand (7%), ankle/feet (7%) and knees (7%). The study revealed the weight handled by workers for both activities were lower than RWL except RWL (destination) for the lifting and lowering front bumper. Meanwhile, LI for lifting and lowering tire was lower than 1.0 indicates the risk was nominal. However, LI for lifting and lowering front bumper was greater than 1.0 poses the condition of the activity more likely to cause risk for a majority of healthy workers. Necessary intervention must consider includes reducing vertical and horizontal distances, eliminated repetitive lifting and lowering and used applicable mechanical aids if necessary.

Keywords: *Lifting; Lowering; NIOSH Revised Lifting Equation; assessment*

INTRODUCTION

The industrial development in developed and developing countries drives numerous occupational-related injuries and diseases including Work-related musculoskeletal disorders (Deros, Darina, Daruis, & Mohamed, 2015; Nur, Dawal, & Dahari, 2014; Spallek, Kuhn, Uibel, Van Mark, & Quarcoo, 2010). Automotive is one of the major industries in Malaysia that provides noteworthy revenues to the government. This industry encompasses various types of activities includes initial design and development, production of automotive parts such as doors, floor elements, mask, roof, fenders (Alszer, Krystek, & Bysko, 2017) and the final stage of the process is installation of parts at the assembly line.

Automotive workers usually exposed to a sort of working conditions that could generate Work-related musculoskeletal disorders, WRMSDs (Deros, Dian Darina Indah Daruis, Ahmad Rasdan Ismail, Nurfarhana Abdul Sawal, & Jaharah A. Ghani, 2010; Knapik & Marras, 2009; Nur et al., 2014) such as back pain, shoulder impingement and neck discomfort due to manual material handling works. For example; a high prevalence of lower back pain among automotive workers were influenced by the types of activity, body postures and movements during their working conditions (Anuar, Nurulakhmar, Mazrura, & Azhar, 2010).

Globally, lifting heavy loads was listed as the main contributing factor that generates low back pain injury (Bernard, 1997; Bevan, 2015; Hoogendoorn, van Poppel, Bongers, Koes, & Bouter, 1999). An experimental study involves part assembling activity found there was a significant association between back pain and peak spinal load (Neumann et al., 2001). Improper manual lifting and lowering were considered as significant risk factors of low back pain (Abdul Majid, Mohamaddan, Omiya, & Notomi, 2016). This phenomenon was rising progressively. The workers were often required to lift and lower loads with incorrect body postures

repeatedly for prolonged working periods. Hence, the present study aimed to:

1. Calculate Recommended Weight Limit (RWL) and Lifting Index (LI) of lifting and lowering activity using NIOSH Revised Lifting Equation,

2. Determine the prevalence of Work-related musculoskeletal disorders (WRMSDs) symptom for lifting and lowering activity.

METHODS

National Institute for Occupational Safety and Health (NIOSH) Lifting Equation

NIOSH Lifting Equation is an approach to evaluate and designing lifting tasks to help decrease the risks of low back injury among workers. The first details technical guideline to control work-related back injuries was back in 1981 published by NIOSH U.S. aims to identify specific risk factors and necessary control methods and ergonomic solutions (NIOSH, 1981) in reducing physical the stress associated with manual lifting and lowering. The equation was revised in 1991 and the latest in 1993 (Waters, Putz-Anderson, & Garg, 1994; Waters, Putz-Anderson, Garg, & Fine, 1993) reflected the previous equation with included some consideration of additional components such as asymmetrical lifting posture and load coupling criteria. Indeed, the NIOSH Revised Lifting Equation (refer equation 1) is a useful method to evaluate physical risk factors involving lifting and lowering activities and it is widely used by the professional ergonomists and researchers (Dempsey, McGorry, & Maynard, 2005). NIOSH Revised Lifting Equation (NRLE) was computed from a straightforward mathematical equation requiring evaluation of six variables that depict the job (Lu, Waters, Krieg, & Werren, 2014). This equation was validated with a strong basis of research findings from biomechanics, psychophysics, and physiology (NIOSH, 1981; Waters et al., 1993). The product of the equation produced Recommended Weight Limit (RWL) for each lifting undertaking by the workers and then provides the Lifting Index (LI) to determine an estimated physical stress level. As an indication, LI values less than 1.0 demonstrates a non-significant risk among healthy employees. Meanwhile, LI greater than 1.0 or more indicates the task is risky and not tolerable. In addtion, LI greater than 3.0 is considered high-risks and the task should stop immediately and re-design.

$$RWL = LC \times HM \times VM \times DM \times AM \times FM \times C \quad (1)$$

Whereas;

LC = Load constant (23 kg), H = Horizontal location of the object relative to the body, V = Vertical location of the body object relative to the floor, D = Distance the object moved vertically, A = Asymmetry angle or twisting requirement, F = Frequency and duration of lifting activity, C = Coupling or quality of the workers grip on the object and M = Multiplier.

The values of each task multiplier (HM, VM, DM, AM, FM and CM) are an important part to consider in evaluating ergonomic design or redesign solutions. According to (Waters et al., 1994):

- If VM < 1.0, Thus, raise or lower the origin/destination of the lift.
- If HM < 1.0, Thus, bring the load closer to the worker. Remove any horizontal barriers or reducing the size of the object. Lifts near the floor should be avoided. In unavoidable, the object should fit easily between the legs.
- If DM < 1.0, Thus, reduce the vertical distance between the origin and the destination of the lift.
- If AM < 1.0, Thus, move the origin and destination of the lift closer together to reduce the angle of twist or move the origin and destination further apart to force the worker to turn the feet and step, rather than twist the body.
- If FM < 1.0, Thus, reduce the lifting frequency rate, reduce the lifting duration, or provide longer recovery periods.
- If CM < 1.0, Thus, improve the hand-to-object coupling by providing optimal containers with handles or handhold cutouts, or improve the handholds for irregular objects.
- If RWL at the destination is less than at the origin - Eliminate the need for significant control of the object at the destination by redesigning the job or modifying the container/object characteristics.

Despite of the advantages to evaluate physical stress and provide solutions of manual material handling activity, some limitations of this

equation identified: (1) NRLE cannot be used for one-hand lifting/lowering activity, (2) NRLE not suitable for lifting/lowering over 8 hours per day and (3) NRLE cannot be used for the activity involves pulling and pushing.

Standard Nordic Questionaire

Work-related psychosocial factors were collected using Standard Nordic Questionnaire. Standard Nordic Questionnaire (SNQ) is a self-report instrument and useful in collecting data related to workplace exposure to physical factors. The SNQ was developed by a team of Nordic researchers aims to assess the severity and impact of musculoskeletal symptoms in selected occupational groups as a part of ergonomic programs and for epidemiological studies of WRMSDs (Kuorinka et al., 1987; Pugh et al., 2015). This method is straightforward and applicable to a wide range of working conditions (Nur et al., 2014) ranging from manufacturing, construction and automotive sectors. The SNQ was translated from English to the Malay language for better understanding among respondents in the Malaysian context.

Camera and measurement scale

To support data collection, additional equipment used during site measurement including camera and measurement scale. The video snapshot concept was an approach to gather picture frames during site assessment (Dempsey et al., 2005) and it is widely used by ergonomists and safety and health practitioners. Whereas the measurement scale was used to measure the horizontal and vertical location of the load and the distance during lifting and lowering activities.

Subject recruitment and study design

A Cross-sectional study examines the prevalence of musculoskeletal disorder and manual material handling (lifting and lowering) among automotive workers in Pekan, Pahang. Workers were selected from two types of activities related to car component installation, which are Lifting and lowering tires (body assembly department) and Lifting and Lowering Front Bumper (Logistics Department).

Written informed consent was obtained voluntarily from the respondents. The confidentiality of personal data was maintained throughout the study period. Data collection was performed during the working period and at the time agreed by the workers and their respective supervisors.

RESULTS

The case study comprised of 120 subjects was selected from body assembly and logistics departments. All of them give their consent and responded to the questionnaire.

Task analysis using NIOSH lifting equation

In the present study, two types of activities were selected evaluated, 1) lifting and lowering tires and 2) lifting and lowering the front car bumper. For the reason of compactness of presentation, the present study took two examples from 120 of assessment and summarized in this paper.

Lifting and lowering tires (Body Assembly Department)

Task analysis: This activity required a worker to grab with both hands, then lift and carry to the main car body assembly area. The tire weight was 8 kg. In this particular activity, the main respondent body parts involved were shoulder, both forehands and fingers to hold the load. Meanwhile, the torso (upper and lower back) significantly involved during the lifting and lowering process. Slightly awkward back posture was observed during lowering the load but not greater than 20° torso flexion. The torso flexion more than 20° considered awkward and significantly contributes to low back discomfort.

The measurement values and corresponding multipliers have been summarized in table 1.

Table 1 Measurement values and multiplier for lifting and lowering tire at body assembly department

	Value	Multiplier
Actual weight	8 kg	-
H-origin	35 cm	0.69
V-origin	80 cm	0.99
H-destination	32 cm	0.78
V-destination	70 cm	0.99
D-distance	10 cm	1.00
Asymmetric	0	1.00
Frequency	6 times	0.75
Duration	1 hour	-
Coupling	Good	1.00

Recommended Weight Limit (RWL) both at origin and destination summarize as below:
RWL origin: 23 x 0.69 x 0.99 x 1.00 x 1.00 x 0.75 x 1.00 = **11.78 kg**

RWL destination: 23 x 0.78 x 0.99 x 1.00 x 1.00 x 0.75 x 1.00 = **13.32 kg**

Lifting Index (LI)

LI origin: 8/11.78 = **0.67**

LI destination: 8/13.32 = **0.60**

The RWL both at origin and destination were higher than the tire actual weight (11.78 kg and 13.32 kg > 8 kg). Meanwhile, the LI's value was less than 1 both at origin and destination (0.67 and 0.60 < 1).

Lifting and Lowering Front Bumper (Logistics Department)

Task analysis: The task requires a worker to pick the front car bumper, grabbing with both hands, lifted and carrying the load before put it on another assembly platform. The weight of the front car bumper was 4 kg. The main respondent's body parts involved were hands, fingers and neck. Meanwhile, the torso (upper and lower back) was significantly involved during the lifting process and lowering process.

The measurement values and corresponding multipliers have been summarized in table 2.

Table 2 Measurement values and multiplier for lifting and lowering front bumper activities

	Value	Multiplier
Actual weight	4 kg	-
H-origin	25 cm	0.89
V-origin	37 cm	0.69
H-destination	40 cm	0.63
V-destination	80 cm	0.99
D-distance	0	1.00
Asymmetric	0	1.00
Frequency	10 times	0.26
Duration	Prolonged	-
Coupling	Good	1.00

Recommended Weight Limit (RWL) both for origin and destination summarize as:

RWL origin: 23 x 1.00 x 0.69 x 1.00 x 1.00 x 0.26 x 1.00 = **4.13 kg**

RWL destination: 23 x 0.63 x 0.99 x 1.00 x 1.00 x 0.26 x 1.00 = **3.72 kg**
Lifting Index (LI)

LI origin: 4/2.85 = **1.40**

LI destination: 4/3.72 = **1.08**

The RWL at origin was slightly higher than the actual weight (4.13 kg > 4 kg). Meanwhile, the RWL at the destination was less than the actual weight (3.72 kg < 4 kg). LI was greater than 1 at origin and slightly higher at destination (1.40 and 1.08 > 1).

Prevalence of Work-related Musculoskeletal Disorder Symptom

Among 120 respondents 17 were reported to experience WRMSDs symptoms at least at one part of the body (figure 1). The prevalence of musculoskeletal disorder symptoms among automotive workers was 14.2%. Specifically, the lower back was the highest prevalence rates (39%) followed by shoulder (14%), upper back (11%), elbow (11%), neck (7%), wrist/hand (7%), ankle/feet (7%), knees (7%), and no reported for hips/thigh.

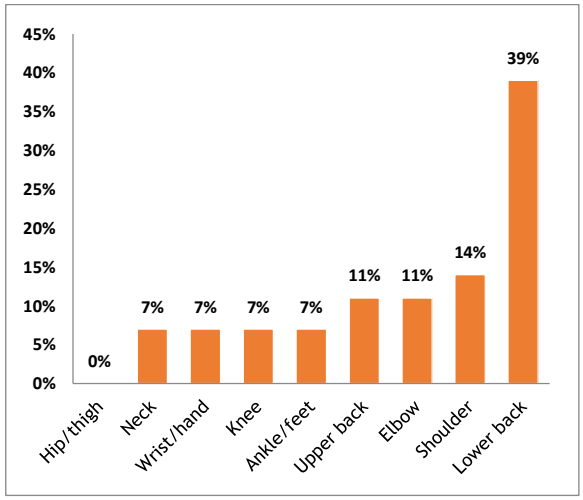

Figure 1 Prevalence of work-related musculoskeletal disorders (WMSDs) symptom at specific body parts among automotive workers (n = 17)

DISCUSSIONS

The present study investigates the potential manual material handling risk factors (lifting and lowering) and WRMSDs symptom among automotive workers. Although the findings from this study did not provide conclusive evidence of the manual material handling risk factors for the

automotive working population, nevertheless, the output would contribute at least some profiling about the risk of lifting and lowering activities for two types of activity aforementioned. Overall, the average loads lifted by the workers for both activities were 8 kg (lifting and lowering tire) and 4 kg (lifting and lowering front bumper) respectively. Meanwhile, the RWL for both activities at origin and destination was 11.78 kg, 13.32 kg, 4.13 kg, and 3.72 kg respectively. These results revealed the presence of loads were lower than RWL calculated (Load < RWL) except for the RWL (destination) for lifting and lowering front bumper. For LI, lifting and lowering tire showed less than 1.0 explained the activities were considered at nominal risk or no chances of a low back injury. Thus, it might not develop adverse effects among healthy workers. In contrast, lifting and lowering front bumper showed LI value greater than 1.0 poses the condition of activity more likely to cause risk for a majority of healthy workers. This finding benefits practitioners especially ergonomists in predicting the risk of a back injury. Based on the study by Marras, Fine, Ferguson, & Waters (1999), LI was found to be predictive of low back injury risk and sensitive to identify the high-risk manual material handling jobs.

Moreover, the present study found that the load position was placed slightly lower from a safe lifting zone (between shoulder and knees) that required workers to bend awkwardly. This comes to the idea of load vertical location as a major component of the RNLE during origin and destination. The VM value for both activities was less than 1.00. This value plays an important role in showing the state of body posture during lifting and loading activities. Tall workers having difficulty when bending awkwardly and it was created more risky conditions especially for those in the average 170 cm tall. Meanwhile, the present study also found that the load for both activities placed horizontally far from the worker's body centre of gravity. Both activities show HM value was less than 1.00.

These findings suggest appropriate control measures should emphasize both activities at the origin and destination. Regarding the NRLE multiplier output, any specific multiplier values less than 1 should consider for task design or redesign. Therefore, for lifting and lowering the front bumper, the lowest specific multiplier was FM, followed by HM (destination), VM (origin), HM (origin) and VM (destination). Whereas for lifting and lowering tires activities, HM showed the lowest multiplier followed by FM, HM (destination), VM (origin) and VM (destination). Based on the facts obtained, the design or redesign task should take into account includes:

1. Reduce repetitive lifting by planning activities accordingly.
2. Reduce the distance of the horizontal load placement at the origin and destination.
3. Reduce the vertical distance of the load at the origin and destination.

Besides, using engineering approaches such as applying mechanical aids to transfer loads is encouraged as far as practicable.

Meanwhile, for body discomfort result, the prevalence showed that the highest discomfort and pain experienced by the workers were lower back. Findings from present study support reports in several previous studies either prospective, epidemiological or systematic reviews (Anuar et al., 2010; Balague, Mannion, Pellisse, & Cedraschi, 2012; Bernard, 1997; Labbafinejad, Imanizade, & Danesh, 2016; Latza, Pfahlberg, & Gefeller, 2002; Wai, Roffey, Bishop, Kwon, & Dagenais, 2010).

On the point of physiological state, working postures in lifting and lowering tasks were stressful, since these activities acquired workers to bend the torso in awkward positions to pick up the load from a low-level surface e.g. material on the ground. Lowering the load was far greater risk compared to lifting in terms of spinal loading (Davis & Marras, 1998). They suggested lowering strength to be 56% greater than lifting strength. It can be seen that the spinal loading during lowering is more than half of the lifting strength. This explanation might help researchers or ergonomists to re-think that lowering task would influence significantly to lower back discomfort and injury rather than lifting. We would suggest the necessary ergonomic solution should be identified for lowering activity as well. Besides, Chowdhury Salian, Boricha, & Yardi, (2012) explained that at the point when the lumbar spine was flexed there was compression of abdominals and stretching the back extensors. Due to prolonged stretching of back extensors, the lumbar spine is put under a mechanical deprivation.

In summary, the result of the self-reporting job-related pain confirmed that lower back pain was the most frequent pain experience among automotive workers and it was due to the combination of awkward back posture and loads factor (David, Woods, Li, & Buckle, 2008).

Limitations and suggestions

Variability of the occupational setting in the workplace could lead to the difficulty of measurement and data collection. Each task and worker has different styles and it was occurring spontaneously. The researchers demand to manage the issue appropriately in ensuring no interference to the work processes and therefore, the objectives of data collection is achieved. We profoundly suggest further study utilizing additional types of ergonomic assessment to obtain more robust output, for instance, combining observational and quantitative strategies or utilize experimental study to validate the output. Furthermore, lifting and lowering were not the only musculoskeletal disorder risk factors. It is possible due to different factor that is observed in automotive activities such as pushing, pulling and several more since workers are not exclusively limited to conduct lifting tasks. In the point of risk management, effective control measures and prevention of back injury should apply according to the principles of OSH risk management inclusive hierarchy of risk controls (Shamsudin, Vijaykumar, & Md Daud, 2017).

CONCLUSIONS

In conclusion, the present study explained:

- Lifting and lowering tire is categorized as safe lifting conditions (LI < 1.0). Nevertheless, lifting and lowering front bumper poses conditions of the activity more likely to cause risk for the majority of healthy workers (LI > 1.0). The calculated LI predicts the relative magnitude of physical stress. Lower LI indicates less stress on workers and contrarily, higher LI indicates the task was risky and intervention step should consider.
- The average load sustains by the workers was acceptable. Whereas the load was less than recommended weight safe to lift except the RWL (destination) for lifting and lowering front bumper.
- Workers experienced WMSDs symptom at least one specific body part. The lower back shows the highest.

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COMPETING INTERESTS

There is no conflict of interest.

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