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ScienceDirect

Procedia Manufacturing 3 (2015) 4927 – 4934

Procedia MANUFACTURING

6th International Conference on Applied Human Factors and Ergonomics (AHFE 2015) and the Affiliated Conferences, AHFE 2015

Improving and modifying the design of workstations within a manufacturing environment

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Abstract

Manual assembly tasks are widespread in many production facilities. However, the manual tasks are often linked to workstations that are not ergonomically designed, which can lead to work-related musculoskeletal disorders (WRMDs). These may result in low productivity, deterioration of worker performance, and issues affecting quality. The first aim of this research project is to analyze the various work postures associated with manual assembly work, within a plastics manufacturing company. The analysis of these work postures will help in understanding the ergonomic conditions of different workstations within the company. The second aim of this project is to study the OSHA incident reports and determine whether correlation exists between a specific workstation and specific body parts. The ultimate objective of this research is to find solutions and to recommend changes that improve the workstations. One way this can be accomplished is by taking ergonomic measures that can be used to evaluate working postures and physical workloads for manual assembly tasks to prevent ergonomic injuries which may lead to WRMDs. This is expected to result in improved productivity, better product quality, and lower medical costs.

Peer-review under responsibility of AHFE Conference

Keywords: Work-related musculoskeletal disorders; Ergonomic injuries; Workstation

1. Introduction

Ergonomics has become a very essential health and economic practice in the workplace. The application of ergonomic programs has gained popularity; since implementation of such programs have addressed increasing medical expenses, higher workers' compensation claims, and the lower productivity due to worker physical injury

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Peer-review under responsibility of AHFE Conference
doi:10.1016/j.promfg.2015.07.631

and pain [1]. The increased frequency of musculoskeletal disorders (MSDs) accentuates that an improper workstation design can enhance the chances for more injuries and result in less job satisfaction and productivity [2]. Implementation of effective ergonomic programs on various workstations should aid in reducing injuries and better physical health [2].

The US Bureau of Labor and Statistics (BLS) underlined that WRMDs amongst assembly workers is an increasing trend when compared to other jobs. US companies that utilize manual assembly tasks spend billions of dollars on lost productivity due to work-related musculoskeletal disorders. These billions of dollars can be explained by insurance bills, hiring and training of new staff, worker compensation, and law suits. The quality of a product is associated with how a worker performs his/her job. A number of experimental studies have developed a relationship between ergonomically problematic work tasks and the quality of a product within assembly work [3].

This research focuses on a plastics manufacturing company's three year record of OSHA recordable injuries. The company manufactures tapes for many industries, which include the following; industrial, building and construction, abatement, laminating, heating, and cooling. The company has 50 years of experience and manufactures 20 different types of tapes for its clients.

Workers within a plastics manufacturing company experience injuries which are categorized as first aid or ergonomic-related, which may lead to WMSDs. Ergonomics, not initially considered in designing the workstations within the company, is now being examined as a better way to reduce employee injuries. The scope of this project is to limited to making recommendations on how to ergonomically improve and modify the design of workstations that are involved with the milling, banburying, calendaring and slitting processes.

2. Ergonomic injuries within the manufacturing industry

The manufacturing industry is comprised of establishments involved in the mechanical, chemical, or physical transformation of substances, materials or components into new products. In 2005, 11.1 % of workers in the United States were employed within the manufacturing industry. These workers manufactured a considerable variety of items, which were not limited to: food products, consumer electronics, automobiles, and plastic products. It has been estimated that there were 15.9 million people within the Manufacturing workforce in 2008, which accounts for almost 10.9% of the total US workforce [4]. While in 2012, there were 125,280 people in the manufacturing industry, and this comprised about 10.85% of the total workforce amongst all industries [5].

In 2008, there were a total of 1,078,140 nonfatal injuries within the private industry. However, there were 8,030 nonfatal injuries that were listed as plastics product manufacturing. Of these nonfatal injuries, 37.3 % (3,000) were due to contact with objects, 16.9% (1,360) falls, 2.24% (280) slips and trips , 20.04% (1610) due to overexertion and 6.4% due to repetitive motion (520). In 2012, there were a total of 918,729 nonfatal injuries within the private industry. There were 6,180 nonfatal injuries that were listed as plastics product manufacturing. Of these nonfatal injuries, 42.88% (2650) were due to contact with objects, 13.75% (850) falls, 2.59% (240) slips and trips, 31.55% (1950) due to overexertion and 5.83% (360) repetitive motion [6].

3. Methodology

Ergonomic incident reports collected by the company in years 2011, 2012 and 2013 were used for data analysis. The statistical analyses conducted used chi-square testing and descriptive statistics for categorical data. Descriptive statistics and the chi-square test were performed using Microsoft Excel 2010.

3.1. Chi-squared test on categorical data

The chi-square test enabled the prediction of excessive worker injuries on any one certain workstation. This was done by taking into account the number of hours worked on each workstation, and determining if the test statistic is larger than the chi-square critical value. The chi-square test statistic can be calculated with the following formula [9]:

$$\chi^2 = \frac{\sum (E_i - O_i)^2}{E_i} \tag{1}$$

Where,

E_i = expected values of injuries = $\frac{H_i * O_T}{H_T}$

O_i = observed value of injuries

O_T = total of observed values

H_i = hours worked in area i

H_T = total number of hours worked

If the test statistic is larger than the critical value $\chi^2_{0.05,\ 4-1}$, which is based on m-1 degrees of freedom, then there exists a significant difference between the observed and expected number of injuries. Workstations that have a larger expected number when compared to the observed values, generally have a correlation between a specific body part and a workstation [7].

4. Results

Data analyzed for this study was evaluated for ergonomic injuries. Each workstation was evaluated for the number of injuries and type of injury. The maximum injuries occurred on the Slitting workstation, which can be categorized as lift/push/pull, as seen in Figure 1.

The most ergonomic injuries on the slitting workstation occurred on the hand/wrist (15), back (9), and shoulders (8). Ten ergonomic back injuries and nine hand/wrist injuries were categorized as lift/push/pull at the Banburying workstation. Chi-square tests were performed for significance of overall ergonomic, back, shoulder and hand/wrist injuries and the results are shown in Tables 1-4. Additionally, the hypotheses are given in each case.

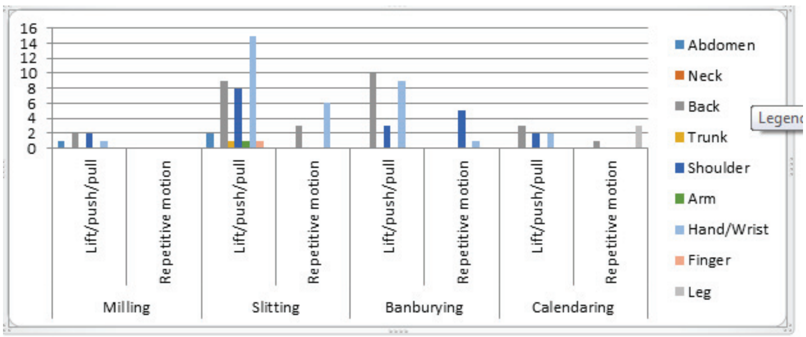

Fig. 1. Ergonomic injuries on all workstations for 2011,2012 and 2013.

Table 1. Chi-square test for 2011, 2012 and 2013 ergonomic injuries by workstation.

Workstation	Injuries (Oi)	Exposure (h)	Expected Injuries(Ei)	P-value	Test statistic	Critical Value
Milling	6	12000	8.754098361	8.86E-10	45.08830628	7.814727903
Slitting	46	36000	26.26229508			
Banburying	26	20000	14.59016393			
Calendaring	11	54000	39.39344262			
	89	122000	89			

H_0: Number of ergonomic injuries do not deviate by workstation for all years based on exposure hours

H_1: Number of ergonomic injuries do deviate by workstation for all years based on exposure hours

H_0 is rejected indicating ergonomic injuries do deviate significantly by workstation based on exposure hours. since the test statistic $\chi^2 = 45.09$, is greater than the critical value $\chi^2_{0.05, 4-1} = 7.81$. The observed number of total injuries on the Slitting workstation is significantly higher (46) than the expected injuries (26.26). Total number of injuries (26) on Banburying workstation is also significantly higher than the expected injuries (14.59).

Table 2. Chi-square test for 2011, 2012 and 2013 ergonomic back injuries data.

Workstation	Injuries (Oi)	Exposure (h)	Expected Injuries(Ei)	P-value	Test statistic	Critical Value
Milling	2	12000	2.754098361	0.002963	13.95767196	7.814727903
Slitting	12	36000	8.262295082			
Banburying	10	20000	4.590163934			
Calendaring	4	54000	12.39344262			
	28	122000	28			

H_0: Number of back ergonomic injuries do not deviate on any particular workstation

H_1: Number of back ergonomic injuries do deviate on at least one particular workstation

H_0 is rejected indicating ergonomic back injuries do deviate significantly by workstation. Test statistic χ^2=13.96 is greater than the critical value $\chi^2_{0.05, 4-1} = 7.81$. The observed number of back injuries on the slitting workstation is significantly higher (12) on the slitting workstation than the expected back injuries (8.26). Total observed number of back injuries is also significantly higher (10) on the Banburying workstation than the expected back injuries (4.59).

Table 3. Chi-square test for 2011, 2012 and 2013 ergonomic shoulder injuries data.

Workstation	Injuries (Oi)	Exposure (h)	Expected Injuries(Ei)	P-value	Test statistic	Critical Value
Milling	2	12000	1.770491803	0.029148967	9.010699588	7.814727903
Slitting	8	36000	5.31147541			
Banburying	6	20000	2.950819672			
Calendaring	2	54000	7.967213115			
	18	122000	18			

H_0: Number of shoulder ergonomic injuries do not deviate on any particular workstation

H_1: Number of shoulder ergonomic injuries do deviate on at least one particular workstation

H_0 is rejected indicating ergonomic shoulder injuries do deviate by workstation. Test statistic χ^2 =9.01 is greater than the critical value $\chi^2_{0.05, 4-1}$ =7.81. The observed number of shoulder injuries on the Banburying workstation are significantly higher (6) than the expected shoulder injuries (2.95).

Table 4. Chi-square test for 2011, 2012 and 2013 ergonomic hand/wrist injuries data.

Workstation	Injuries (Oi)	Exposure (h)	Expected Injuries(Ei)	P-value	Test statistic	Critical Value
Milling	1	12000	3.344262295	2.90523E-06	28.46187364	7.814727903
Slitting	21	36000	10.03278689			
Banburying	10	20000	5.573770492			
Calendaring	2	54000	15.04918033			
	34	122000	34			

H_0: Number of hand/wrist ergonomic injuries do not deviate on any particular workstation

H_1: Number of hand/wrist ergonomic injuries do deviate on at least one particular workstation

H_0 is rejected indicating that hand/injuries do deviate by workstation since the test statistic χ^2 = 28.46, is greater than the critical value $\chi^2_{0.05, 4-1}$ = 7.81. The observed number of hand/wrist injuries on the Slitting workstation are significantly higher (21), than the expected hand/wrist injuries (10.03). The observed number of hand/wrist injuries on the Banburying workstation are also significantly higher (10) than the expected injuries (5.57).

5. Discussion

Analysis of the data showed which workstations have contributed to the most injuries and if any correlation exists between specific body part injuries and a specific workstation. The results substantiates that there are two workstations - Slitting and Banburying - that have significantly contributed to the injuries experienced by the workers. The chi-square tests statistically verified that the workers are suffering from poor ergonomic conditions and stress induced from the manual assembly tasks.

Low back disorders are very common musculoskeletal disorders amongst workers within companies [8]. Moreover, the danger of back failure grows for workers whose tasks consist of lifting with a rotated trunk. Furthermore, it could be observed that the risk of a shoulder injury is common to occur when the workers execute manual assembly tasks that involve pushing and pulling, as do those at the Banburying workstation. Finally, workplace musculoskeletal disorders can occur due to tasks that involved wrist motion and highly repetitive hand motion, as do those at the Slitting workstation [9].

In a study by Nur et al. on workers within the automotive manufacturing industry [10], the results found that the prevalence of MSDs was highest on the neck (49.3%), followed by the hand/wrist (48%), shoulder (46.7%) and back (33.6%). On a similar study done by Hussain on truck assembly workers [10], the results found that the prevalence of MSDs was highest on the neck, followed by the shoulder, hand/wrist and finally, the lower back. The prevalence of MSDs within the shoulders and hand/wrists is due to short cycle time and high production volume [11]. The results are consistent with studies done previously. In 2011, 2012 and 2013 the Slitting and Banburying workstations accounted for 51.7% and 29.2% of total ergonomic injuries, respectively. Sixty-two percent (61.7%) of the hand/wrist injuries, 44.4% of the ergonomic shoulder injuries and 42.8% of the ergonomic upper back injuries were experienced by workers on the Slitting workstation. Furthermore, 29.4% of the hand/wrist injuries, 33.3% of the ergonomic shoulder injuries and 35.7% of the ergonomic upper back injuries were experienced by workers on the Banburying workstation. The chi-squared test statistically established that the 2011 ergonomic injuries did deviate on two particular workstations, and these workstations specifically included the Slitting and Banburying workstations, and the results are recorded in Table 1. The number of back, shoulder and hand/wrist injuries were statistically significant on these two workstations, and the results are recorded in tables 2-4. Since all the workers within this company are executing highly repetitive industrial tasks, they could possibly experience MSDs in the future, due to cumulative exposure to these tasks.

In 2012, there a total of 54 nonfatal injuries within this plastics product manufacturing company. Of these nonfatal injuries, 37% (20) were due to overexertion and 12.96% (7) repetitive motion. These results are consistent with the results provided by BLS for 2012.

Fig. 2. Bags of resin.

Fig. 3. Turntable on a load leveler [12].

During the Banburying process, the worker repeatedly prepares 50 batches of adhesives, each weighing between 205-250 kgs. These batches primarily contain bags of rubber and resins that weigh approximately 23 kgs, as well as, other oily substances for the adhesive. Then another worker places these batches of adhesives onto pans that have been loaded on pallets, as shown in Figure 6. The constant placement of these batches on the conveyor belt as shown in Figure 3 and the placement of pans on pallets causes the back to suffer twisting and bending from the 90 degree turn, which cumulatively can lead to back disability or a MSD. Moreover, the shoulder experiences constant flexion due to jerky movement and can over time lead to bursitis. Statistical results indicate that the manual assembly tasks are very demanding on the back, shoulders and the wrist. It is vital that engineering controls be implemented to prevent workers from experiencing serious issues, such as musculoskeletal disorders, over time.

During the Slitting process, a team of two consistently engage in repetitive work with lifting spindles with tape and spindles without tape, weighing 18 and 9 kgs, respectively. The team handles about 600 spindles with tape and 600 without tape per shift. The repetitive forceful hand motions forces the palms to undergo constant supination and pronation of the palms as well as wrist rotation. Over time this can result in tenosynovitis or carpal tunnel syndrome. During the process of loading and unloading the spindles, the worker's back experiences a 45 degree swing, which over time can be detrimental to the back and lead to a back disability. Finally, there is a 130 degree lateral swing between the arms and this can be demanding on the shoulders and should be avoided since this could lead to tendinitis or bursitis.

6. Recommendations

In order to reduce the ergonomic injuries on the Banburying and Slitting workstation, it would be necessary to take both engineering and administrative controls. To reduce the stress of workers when lifting from low-working heights as shown in Figure 2, implementing a turntable on a load-leveler could prevent workers from implementing poor lifting techniques such as jerky movement or lifting objects too far away from the body, as shown in Figure 3.

To prevent the worker's back from experiencing a 90 degree twist and putting the shoulders in an awkward position while placing the batches of rubber which weigh 23 kgs, on the conveyor belt as shown in Figure 4, a lifting device could be used. A portable hoist or crane as shown in Figure 5, would prevent back disabilities and other shoulder injuries and musculoskeletal disorders that workers would otherwise suffer [13].

Fig. 4. Placing rubber batches on conveyor belt.

Fig. 5. Portable Hoist or crane [12].

To reduce the exertion faced by the workers when lifting the pans from low-working heights as shown in Figure 6, utilizing a turntable on a load-leveler would prevent the workers from executing poor lifting techniques such as jerky movement or lifting objects too far away from the body, as shown in Figure 7.

Loading pans on pallet exerts a lot of stress within the worker's back and puts the shoulders in a very awkward situation. Investing in lighter pans could help reduce this stress, decrease the number of back and shoulder injuries and musculoskeletal disorders that workers would otherwise suffer. Furthermore, the pans should be loaded with 2 bales of rubber of 5.68 kgs each, rather than 1 bale of rubber that weighs 11.36 kgs, which would relieve stress on the shoulders and back. Finally, while placing the bales of the rubber on the pan, dropping the bundle as opposed to tossing them would help reduce the ergonomic injuries.

Fig. 6. Loading pans on pallet.

Fig. 7. Turntable on a load leveler [12].

7. Conclusions

This research determined there is a correlation between specific workstations and body part injury, by using the chi-square test for categorical data. The chi-square test assisted in proposing what should be effective ergonomic measures that could help reduce the severity of ergonomic injuries that would otherwise lead to possible musculoskeletal disorders. Proposed ergonomic interventions are vital tools in reducing injury costs, as well as increasing worker productivity and better product quality.

Acknowledgements

This research was made possible by the data supplied by the plastics product manufacturing company.

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