CDC Workplace Safety and Health

Ergonomic Evaluation of Workers at a Piston and Cylinder Liner Manufacturing Plant

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ABBREVIATIONS

CLI	Cumulative lifting index
HHE	Health hazard evaluation
LI	Lifting index
MSD	Musculoskeletal disorder
NIOSH	National Institute for Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
RNLE	Revised NIOSH lifting equation
RWL	Recommended weight limit
WMSD	Work-related musculoskeletal disorder

Highlights of the NIOSH Health Hazard Evaluation

The National Institute for Occupational Safety and Health (NIOSH) received a union request for a health hazard evaluation at Federal-Mogul in Lake City, Minnesota. An ergonomics evaluation was performed in March 2007. NIOSH investigators were asked to look at potential ergonomic hazards among workers and make suggestions for workstation design.

What NIOSH Did

- We talked to workers about their work and medical history. We also talked to them about possible work-related musculoskeletal disorders.
- We talked to the plant chiropractor about injuries at the plant.
- We watched and took videos of jobs in the cast iron foundry, aluminum foundry, piston machining, cylinder liner machining, and joint venture areas.

What NIOSH Found

- We found that workers are exposed to risk factors for developing musculoskeletal disorders. These risk factors include high force, awkward postures, and repetitive motions.
- We found that workers reported musculoskeletal pain or discomfort in the low back and shoulders from heavy lifting and awkward postures.

What Federal-Mogul Managers Can Do

- Managers should add adjustable lifts and tables to reduce bending and reaching.
- Managers should allow ample space around materials to reduce reaching.
- Managers should train workers to be aware of unsafe work practices and learn the early warning signs of musculoskeletal disorders.

What Federal-Mogul Employees Can Do

- Employees should report injuries and unsafe work conditions to their supervisors.
- Employees should take part in safety and ergonomic groups.
- Employees should take time to work safely and lift properly.

SUMMARY

Most workers are exposed to a combination of risk factors for developing MSDs. Risk factors included awkward postures and repetitive motions. The use of adjustable tables and improved workstation design would reduce physical stresses and the risk of musculoskeletal injury.

On January 30, 2007, NIOSH received an HHE request from the International Brotherhood of Boilermakers to evaluate potential ergonomic hazards among workers at the Federal–Mogul piston and cylinder liner plant in Lake City, Minnesota. The request was prompted by upcoming redesign of workstations and cells.

On March 8–9, 2007, NIOSH investigators visited the plant in Lake City, Minnesota. On March 8, 2007, NIOSH investigators (ergonomic specialists and a physician) held an opening conference with management, union officials, and the on-site chiropractor who provides medical care to the employees. Ergonomic specialists toured the plant to observe specific piston machining, cylinder liner machining, and foundry tasks. The physician interviewed workers about their medical status in a confidential setting. On March 9, 2007, NIOSH investigators held a closing conference and provided preliminary recommendations.

The ergonomics evaluation indicated that most workers were at risk for developing MSDs from awkward postures and repetitive motions. Additional risk factors in specific areas included vibration and heavy lifting. Of the 26 interviewed workers, 19 reported work-related musculoskeletal pain or discomfort in the previous year. The most common complaints were low back pain and shoulder pain.

Recommendations for reducing the risk of injury are contained in this report, including installing adjustable lifts, tables, and lift assists; and allowing adequate space around pallets.

Keywords: NAICS 336350 (Motor Vehicle Transmission & Power Train Parts Manufacturing), pistons, cylinder liners, foundry, repetitive motions, work-related musculoskeletal disorders, ergonomics, prolonged walking and standing

Introduction

On January 30, 2007, NIOSH received an HHE request from the International Brotherhood of Boilermakers to evaluate potential ergonomic hazards among workers at the Federal–Mogul piston and cylinder liner plant in Lake City, Minnesota. Recent redesign of some workstations into work cells prompted the request.

On March 8–9, 2007, NIOSH investigators visited the piston and cylinder liner plant in Lake City, Minnesota. On March 8, 2007, NIOSH investigators (ergonomic specialists and a physician) held an opening conference with management, union officials, and the on-site chiropractor. Ergonomic specialists toured the plant to observe piston machining, cylinder liner machining, and foundry tasks. The NIOSH physician interviewed workers about their medical status in a confidential setting. On March 9, 2007, NIOSH investigators held a closing conference and provided preliminary recommendations.

Process Description

The Lake City, Minnesota plant was founded in 1868 as a cast iron foundry. Machining of cast iron pistons began in 1939, and production of aluminum pistons started in 1948. The plant began production of cylinder liners in 1983. Federal-Mogul Powertrain Systems acquired the Lake City plant in 1998 and established Federal-Mogul TP Liners, Inc. in 1999. At the time of the NIOSH evaluation, the plant had approximately 500 employees and 350,000 square feet of floor space. Current work performed on-site includes cast iron foundry operations, aluminum foundry operations, piston machining, cylinder liner machining, and a joint venture operation.

Cast Iron Foundry

Approximately 75 people work in the cast iron foundry. Workers in this area use hoists and cranes to perform some material handling tasks. However, they are required to manually lift 50–pound bags of raw materials, and manually place the final product in baskets according to size. Workers also grind castings when the tumbler does not remove all the excess material.

Aluminum Foundry

Approximately 30 people work in the aluminum foundry. This area is less automated than the cast iron foundry. Depending on the size of the part produced, the aluminum mold stations have various manipulators and lift assists. However, operators manually pour the aluminum into the mold at some stations. Other stations have manipulators to help hold the ladle while pouring. For some products, the worker removes the product from the mold using pliers and places it on a conveyor that transports the part from the mold station into a basket. Other stations are equipped with a lift that picks up the part and places it on a conveyor. Workers in the aluminum foundry use hammers to release the product from the mold and to break off excess metal from the product.

Piston Machining

Approximately 80 people work in piston machining. Workers machine aluminum piston castings to size and specifications in this area. They remove rough, forged pistons from a wire basket, mill them on a series of lathes, and place the finished product in either a wire basket or a cardboard box. The piston machining area used to be in line for single piece flow: one worker would machine an entire wire basket of pistons on a particular lathe before transferring to another lathe until all machining was complete. Recently, the company implemented "lean manufacturing" and moved toward a work cell format: a group of workers runs an entire wire basket of pistons through the series of lathes, and the final product is placed in either a wire basket or a cardboard box. As of March 2007, the company had created four work cells in the piston machining area. NIOSH investigators observed piston machining tasks in both the old and new workstation designs, which were located in one of the areas of primary concern for WMSD risk.

Cylinder Liner Machining

Approximately 180 people work in cylinder liner machining. Workers machine cast iron liners to finished product specifications in this area. The company has liner work centers, but they are not standardized. Recently, following a cycle time analysis of an area, two work cells were combined into a work center (712/713) to improve work flow. This was another area of primary concern regarding risk for MSDs, and NIOSH investigators observed the combined tasks in the 712/713 area. This area is capable of machining both the Lake City castings (made in-house, requiring boring) and Mexico castings (made in Mexico, pre-bored). Two different castings are machined at the same time; one workers runs all the machines. In this area, the worker retrieves rough forged cylinder liners from a pallet. The worker then mills the liner on a series of bores and lathes, checks it for calibration, and places it in a wire basket.

Joint Venture

Approximately 90 people work in the joint venture area. This area is a result of an agreement for a joint venture between Federal–Mogul and Teikoku Piston Ring Co., Ltd. Although this area has a different plant manager, Federal–Mogul is responsible for environment, health, and safety for the entire facility, including the Joint Venture area. Centrifugal systems create long tubes that are cut to size to produce a high volume of cast iron liners. Automated machining lines operate side-by-side, and workers manually handle materials only during gauging and inspection.

Onsite Employee Health Clinic

A contracted chiropractor with industrial ergonomics training staffs the on-site employee health clinic 2 days per week. The chiropractor examines employees who report symptoms and evaluates their workstations. Based upon these results, he writes a report to the company and specifies needed light duty work restrictions. The chiropractor refers employees for further evaluation to a physician if the musculoskeletal symptoms persist.

Ergonomic and Safety Committees

Each production department has a safety team. These teams address safety and ergonomic issues on a weekly basis. The teams are cross-functional, composed of management, engineers, union operators and union safety representatives. The plant safety and ergonomic committee consists of a union safety representative from each production department and the Environment, Health, and Safety Coordinator. This team meets on a monthly basis.

Assessment

NIOSH investigators toured the foundry, assessing machining tasks to observe the processes of cast iron molding, aluminum molding, machining pistons, and machining cylinder liners. They also observed tasks in the joint venture area. Specific jobs in the piston machining and cylinder liner machining areas were selected for evaluation based upon conversations with management and labor representatives regarding the recent redesign of these work areas. Appendix A contains a description of the ergonomics evaluation criteria the investigators used. NIOSH investigators recorded digital videos, measurements of workstation heights, and measurements of reach distances to document the tasks performed by the workers. They reffered to the Washington State Caution Zone Checklist regarding hand and arm vibration exposure [Washington State Department of Labor and Industries 2008]. The investigators used the RNLE [Waters 1994] to assess the physical demands of lifting tasks in the cylinder liner machining area. A full description of the components of the RNLE is provided in Appendix B. In brief, the equation provides RWL and LI for a lifting task, given certain lifting conditions. The RWL is the weight that can be handled safely by almost all healthy workers in these conditions. The LI is the ratio of the actual load lifted to the RWL. Tasks with an $LI > 1.0$ may place an increasing number of individuals at risk of low back injury, and tasks with an $LI > 3.0$ pose a risk of back injury for most workers. Lifting tasks with an $LI \leq 1.0$ pose little risk of back injury for most workers. The key to interpreting the risk of injury for a given LI is to understand how injuries increase as the LI increases. A cross-sectional epidemiologic study conducted by NIOSH indicated that as the LI increased for 204 workers performing 50 different lifting jobs in four different industrial facilities, the prevalence of reported back pain also increased [Waters 1999]. The prevalence of back pain lasting a week or more was highest for workers performing lifting jobs in the $2 < LI \leq 3$ category, nearly twice that of workers in non-lifting jobs. The risk of injury for jobs in the $1 \leq LI \leq 2$ category was higher than for non–lifting jobs but the increase in risk was not significant due to small sample size. The main conclusion of the study was that while more data are needed, the best approach to injury prevention is to design jobs for workers that result in LIs ≤ 2.

All current employees of Federal–Mogul had been invited to participate in confidential interviews prior to the site visit. NIOSH investigators provided advanced notification regarding the HHE medical interviews to both the management and union for dissemination to the employees several weeks before the site visit. An interview schedule was prepared jointly by the union and management ahead of the site visit. Workers were asked questions about their job and if they had any musculoskeletal pain over the past year that they thought might be work–related. If they reported pain over the previous year, additional questions were asked regarding location of pain and tasks associated with the pain. Employees were also given the opportunity to voice any other health and safety related concerns regarding their work at Federal–Mogul.

Cast Iron Foundry

Various areas of the cast iron foundry pose risks for musculoskeletal injury. At the beginning of the cast iron process, workers manually lift 50–pound bags of raw carbon and silica to make batches of iron. Each batch requires lifting four bags (200 pounds); approximately seven batches are prepared per shift, totaling 28 bags (1120 pounds). Pallets of raw materials are placed directly on the floor. Extended reaches, especially when lifting the last row of material located directly on the floor, exacerbate the potential fatigue from handling the large amount of weight.

Another area that poses a musculoskeletal risk is at the end of the cast iron process. Workers sort the product into wire baskets according to size. The current layout (Figure 1) requires workers to twist to place products into the baskets. Also, the wire baskets are not height adjustable, requiring workers to reach into the basket when placing the bottom rows of product.

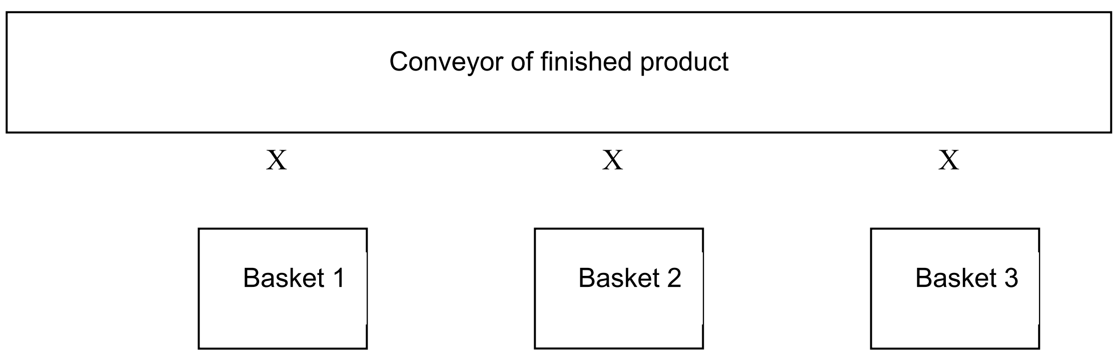

Figure 1. Current layout of sorting cast iron products (X represents a worker's location)

At the end of the conveyor line, workers grind pieces not adequately removed by the tumbler at two stations. One station's layout was a result of suggestions from a previous NIOSH HHE [NIOSH 1995]. Parts–in and parts–out baskets, with tilt lifts, are located on either side of the grinding station. The parts-in basket still poses a risk for musculoskeletal stress to the back due to extended reaches into the basket. The worker is also potentially exposed to hand-arm vibration, due to using a pneumatic vibrating tool during the workday.

Aluminum Foundry

The major stressors observed in this area are from the static awkward postures of the hands, wrists, and arms as the workers pour aluminum from the ladle into the mold. Static posture and strength required to slowly, carefully pour the aluminum causes stress on the wrists and hands. Another stressful job element was removing the aluminum piston from the mold with pliers and placing the piston on a conveyor. Automation would remove these stressors; however, most stations are not automated, and these steps are still performed manually.

Piston Machining

The major musculoskeletal job stressors observed for piston machining were to the upper limbs and back. The initial lift from the wire basket often required extended reaches. The reach varied from station to station and product to product. Incoming baskets at the beginning of piston machining cells did not have adjustable lift tables. Musculoskeletal fatigue due to the total amount of weight handled by the operator each day exacerbated the stress of extended reaches. The end of the machining line where workers placed the finished product into wire baskets or cardboard boxes had the same extended reach stressor. Outgoing baskets and boxes at the end of piston machining process did not have adjustable lift tables. However, one station did have the cardboard box raised on a wheeled cart. This position still required the worker to reach when placing the first/bottom row of product into the box or to walk around to the far corner and still reach down into the box. A few of the work cells were equipped with shadow boards that held tools needed to change dies and work on the machines. These had replaced traditional toolboxes that took up space and required workers to bend down to retrieve parts and tools. However, several stations still had toolboxes.

Cylinder Liner Machining

Management asked the NIOSH investigators to evaluate the recently combined 712/713 cylinder liner work center. The two work cells were combined to improve workflow; however, management was considering rearranging the work due to concerns about excessive walking between the machines. During the week of the NIOSH site visit, the worker in the cell was machining "Mexico" castings. The area was equipped with a tilt table, but it could not be used with the Mexico castings because they arrive at the plant stacked and shrink–wrapped (the parts would fall over if the current tilt table was used). Lake City castings, the other castings typically machined in this area, are made in-house and can be transported through the plant in wire baskets that can use the current tilt table.

One worker performed all of the tasks in the 712/713 work center (24 movements, 17 lifts, 0.5 lifts per minute). This consisted of lathing two cylinder liners simultaneously, transporting each liner from the pallet through the series of machines, and placing it in the outgoing wire basket. Management also provided two proposed cycle time analyses that they were considering implementing. Proposal #1 had 32 total movements and 23 lifts (0.33 lifts per minute); proposal #2 had 32 total movements and 19 lifts (0.44 lifts per minute). A description of the RNLE evaluation performed on the 712/713 work center is provided in Appendix C. CLIs were calculated with respect to the current cycle time analysis, the proposed cycle time analyses provided by management, and for the individual cells (9 lifts from the current cycle time analysis, 0.5 lifts per minute) (Table 1). An example of the assumptions that were made for calculating the lifting indices for the current cycle time analysis are provided in Appendix D.

Every lifting job task evaluated in this area exceeded the recommended LI of 1.0, but none surpassed an LI of 3.0, considered hazardous for nearly all workers. Both of the proposed cycle time analyses had higher CLIs than the current cycle time analysis. The CLI for the individual cell was much lower (almost half) than the combined work center. The current and proposed cycle times had LIs between 2.1 and 2.8, indicating an elevated risk of injury as compared to jobs that have an LI ≤1.0.

Note that the calculation of the lifting index does not take into

Table 1. CLIs for Cylinder Liner 712/713 Work Center

Layout options	CLIs
Current cycle time analysis	2.1
Proposal #1 cycle time analysis	2.8
Proposal #2 cycle time analysis	2.8
Individual work cell analysis	1.1

consideration the fatigue associated with the amount of walking required in the 712/713 work center during the shift. To get a better indication of the stress associated with this job, a metabolic analysis (including heart rate) would be required; this was beyond the scope of the HHE.

Joint Venture

The major musculoskeletal stressor observed in the joint venture area was shoulder extension during the gauging process. Transfer of the part into the gauging instrument required that the workers extend the right shoulder due to the workstation design. In addition, the bin for defective pieces was located 7 to 10 feet behind the worker, so they had to toss the part behind them using their left hand, which caused extreme left shoulder extension. The repetitive motion of both of these shoulder postures may cause pain and discomfort to these workers.

Employee Interviews

All but one of the 26 employees interviewed were male. The average age of these employees was 45.5 years with a range of 23 to 65 years. The average duration of employment at Federal-Mogul was 19 years. Participants came from all areas of the facility with 11 from the cylinder liner machining area, 7 from the piston machining area, 3 from the aluminum foundry, 2 from the cast iron foundry, 2 from the joint venture area, and 1 who worked throughout the plant. Only 6% (26/445) of workers in the areas evaluated were interviewed. This was a convenience and not a random employee sample. The employees were selected for interview jointly by the management and union in order to minimize disruption of the production line but still include employees who had disparate opinions on workplace conditions.

Seventy-three percent (19/26) of participants reported having musculoskeletal pain or discomfort in the previous year that they believed was associated with their work. The most common complaints were low back pain and shoulder pain that employees associated with lifting heavy parts and having to bend at odd angles. In the last 2 years, workers compensation has paid nine claims for lower back strain/sprain; nine claims for shoulder strain/sprain; and one for carpal tunnel syndrome.

Results and Discussion (continued)

All but one employee reported routinely working more than 40 hours per week. The company had a compulsory overtime policy requiring working 10 hours each day instead of 8 hours during the workweek, working four consecutive Saturdays before having one off, and working every other Sunday. This policy went into effect when orders became backlogged to provide timely shipping to customers. Employees mentioned that this policy had also become more frequently used due to reductions in the workforce at Federal-Mogul over the last few years. Employees reported increased fatigue and musculoskeletal pain during the 6– and 7–day extended overtime workweeks as compared to a 5–day workweek. Although hoists and other lift-assist devices were available at some workstations, several employees were reluctant to use them out of concern that the device would damage their product.

Conclusions

On-site assessments and interviews at the Federal–Mogul plant are the basis for the following conclusions. Most workers at the plant are exposed to a combination of concurrent risk factors for developing upper extremity MSDs: awkward postures, repetitive motions, heavy loads, and inadequate recovery time due to the compulsory overtime policy. The problems with workstation design that place workers at risk for MSD injuries include non–adjustable workstations and lack of space for completing the job tasks.

Most musculoskeletal disorders reported during the NIOSH medical interviews and in workers compensation claims involve the upper extremity and low back.

Recommendations

The preferred method of controlling ergonomics hazards is to provide engineering controls. Engineering controls involve making changes to workstations, tools, and equipment. Engineering controls are preferable because they eliminate the hazard at the source. Administrative controls are designed to limit workers' exposures to hazardous conditions and can be used temporarily until engineering controls are implemented. In addition, changes in work practices can also significantly reduce risk factors for developing MSDs. Training is helpful in allowing employees to participate in the process of identifying hazards and making job modifications.

Engineering Controls

General recommendations that would eliminate or significantly reduce physical stresses in individual areas are listed below.

Cast Iron Foundry

1. Provide adjustable turntables that pneumatically lift and rotate the bags of raw materials and baskets of finished product so they are always closest to the body when lifting. The height of the "working row" of bags should be approximately 30" above the ground [Waters et al. 1994]. The lift should be designed such that the operator can stand as close as possible.
2. Use or modify the alternate layout (Figure 2) to eliminate twisting. The baskets are also not adjustable and require reaching into the basket. Place baskets on adjustable tables to eliminate excessive bending when placing pieces on the bottom row.

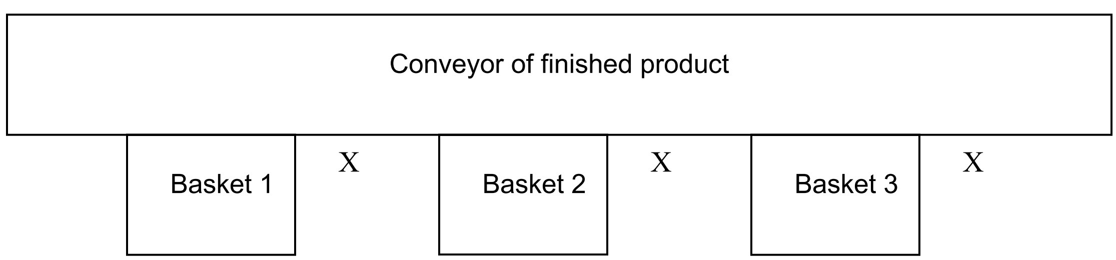

Figure 2. Proposed layout for sorting cast iron products (X represents a worker's location).

3. Reduce vibration exposure by providing tools with low vibration frequencies, properly maintaining tools, scheduling rest breaks to allow for recovery, and alternating work tasks with other tasks that do not involve vibration exposure.

Aluminum Foundry

1. Provide a zero-balance hoist to support the ladle when pouring aluminum into the molds; some workstations already have this equipment.
2. Provide a zero-balance lift device to remove product from the molds and eliminate the use of pliers, which cause awkward wrist postures.

Piston Machining

1. Provide adjustable turntables that pneumatically lift and rotate the baskets of product so they are always closest to the body when lifting. The height of the "working row" of product should be approximately 30" above the ground [Waters et al. 1994]. The lift should be designed such that the operator can stand as close to the basket as possible.
2. Reduce material handling by constructing gravity feed conveyors to move pistons from one station to another.
3. Provide zero-balance lift devices to move heavier pistons from one station to another. NIOSH investigators observed a few of these devices in various areas. Incorporating them in more areas would reduce manual material handling and risk of upper limb and low back pain and injuries.
4. Replace remaining toolboxes with shadow boards to eliminate bending to retrieve tools and parts.

Cylinder Liner Machining

1. Provide adjustable turntables that pneumatically lift and rotate the baskets of product so they are always closest to the body when lifting. The height of the "working row" of product should be approximately 30" above the ground [Waters et al. 1994]. The lift should be designed such that the operator can stand as close to the basket as possible. Reducing the reach distance by adjusting the height of the basket will reduce the LI.

2. Split the 712/713 area back into two individual jobs to minimize the risk of low back pain and injury. This layout had the lowest CLI of all the proposed layouts.

Joint Venture

1. Provide container-handling turntables that pneumatically lift and rotate containers so that cylinder liners are always closest to the body when lifting. The height of the "working row" of liners in the container should be approximately 30" above the ground and 10" or less away from the body. The container lift should be designed such that the operator can stand as close to the container as possible. The lift should also accommodate the variety of containers used in the plant (pallets, wire containers, cardboard boxes) without spilling material (such as tilt tables that cannot be used with palletized materials).
2. Redesign the workstation by adding an extension to the workstation to reorient the worker and eliminate shoulder flexion when performing gauging tasks.
3. Redesign the work area to relocate the scrap container and eliminate shoulder extension when throwing scrap into the container.

Administrative Controls

The effectiveness of administrative changes in work practices for controlling MSDs depends on management commitment and employee acceptance. Regular monitoring and reinforcement are necessary to ensure that control policies and procedures are not circumvented in the name of convenience, schedule, or production. An advantage of administrative controls is that they can be implemented quickly and easily without capital expense. However, because administrative controls do not eliminate the hazard, they should be considered temporary solutions for controlling exposures until engineering controls can be implemented. Administrative control recommendations for all processes/areas include the following:

1. Rotate workers through several jobs with different physical demands to reduce the stress on limbs and body regions.

2. Equip all areas with anti-fatigue mats and/or foot rests to prevent muscle fatigue, low back pain, and stiffness in the neck and shoulders from prolonged standing.

3. Schedule more breaks to allow for rest and recovery. Reassess the compulsory overtime policy to allow weekend recovery time more consistently.

4. Broaden or vary job content to offset certain risk factors (i.e., repetitive motions, static and awkward postures).

5. Train employees to recognize WMSDs and instruct them in work practices that can ease the task demands or burden.

Work Practices

Changes in how workers perform specific tasks can also significantly reduce risks of MSDs. Developing standards and operating procedures are a few ways to achieve this goal.

1. Train workers to slide materials from the center of a container to the edge before lifting. When reaching or moving pistons, cylinder liners, and bags of materials to or from the center of a container or pallet, workers should slide the piece into position, rather than reaching and placing pieces in or from the center.

2. Train workers to use two hands when handling pistons and cylinder liners from the beginning to the end of the work cycle.

3. Train workers to avoid hand pinch postures when transporting pistons and cylinder liners from one workstation to another.

4. Train workers to use zero–lift assist devices properly, and audit use of the devices.

5. Keep equipment well maintained and in proper working order.

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Appendix A: Ergonomic Evaluation Criteria

The term MSDs refer to conditions that involve the nerves, tendons, muscles, and supporting structures of the body. WMSDs are a major component of the cost of work-related illness in the United States. A substantial body of data exists providing strong evidence of an association between MSDs and certain work-related factors (physical, work organizational, psychosocial, individual, and sociocultural). The multifactorial nature of MSDs requires a discussion of individual factors and how they are associated with WMSDs. There is strong evidence that working groups with high levels of static contraction, prolonged static loads, or extreme working postures involving the neck/shoulder muscles are at increased risk for neck/shoulder MSDs [NIOSH 1997]. There is also strong evidence that job tasks that require a combination of risk factors (highly repetitious, forceful hand/wrist exertions) increase risk for hand/wrist tendonitis [NIOSH 1997]. Lastly, there is strong evidence that low-back disorders are associated with work–related lifting and forceful movements [NIOSH 1997]. A number of personal factors can also influence the response to risk factors for MSDs including: age, gender, smoking, physical activity, strength, and anthropometry. Although personal factors may affect an individual's susceptibility to overexertion injuries/disorders, studies conducted in high-risk industries, show that the risk associated with personal factors is small compared to that associated with occupational exposures [NIOSH 1997].

In all cases, the preferred method for preventing/controlling work-related musculoskeletal disorders is to design jobs, workstations, tools, and other equipment to match the physiological, anatomical, and psychological characteristics and capabilities of the worker. Under these conditions, exposures to task factors considered potentially hazardous will be reduced or eliminated.

The specific criteria used to evaluate the job tasks at Federal–Mogul were workplace and job design criteria found in the ergonomics literature and recommendations for acceptable lifting weights as determined by the RNLE [Waters 1994].

Workstation design should directly relate to the anatomical characteristics of the worker. Since a variety of workers may use a specific workstation, a range of work heights should be considered. Based upon female/male 50^{th} and 95^{th} percentile anthropometric data, workstation heights should be within a range of 27.6" to no higher than 60" [Kroemer 1989]. These heights correspond to knuckle and shoulder dimensions of U.S. civilians, age 20 to 60 years.

Hand and arm vibration is transmitted to workers hands and arms by contact with a vibrating source. Tools commonly used in industry, such as grinders, sanders, and jackhammers, are all sources of vibration. Hand and arm vibration syndrome is characterized by exposure to levels of vibration that lead to symptoms such as numbness and tingling, blanching of the fingers, and carpal tunnel syndrome [Chengalur et al. 2004]. It is recommended that exposure to moderate hand and arm vibration from hand tools be limited to no more than two hours total per day, as per the Washington State Caution Zone Checklist [Washington State Department of Labor and Industries 2008]. If the vibration value for the tool is known, a calculator for hand and arm vibration is also available in the Washington State Hazard Zone Checklist [Washington State Department of Labor and Industries 2008].

The RNLE is a tool for assessing the physical demands of two-handed lifting tasks. The equation provides a recommended weight limit and lifting index for a lifting task, based upon the lifting conditions [Waters 1994]. The RNLE recommends when initiating a lift that the vertical height of the hands above the floor should be 30". A height of 30" above the floor is considered "knuckle height" for a worker of average height. The RNLE also states that in ideal lifting conditions, the maximum recommended weight limit is 51 pounds. Therefore, a worker should not lift anything over 51 pounds without assistance from another worker or using a lift assist device [Waters 1994]. In brief, the equation provides RWL and LI for a lifting task, given certain lifting conditions. The RWL is the weight that can be handled safely by almost all healthy workers in similar circumstances. The LI is the ratio of the actual load lifted to the RWL. Tasks with a LI >1.0 may place an increasing number of individuals at risk of low back injury and tasks with a LI > 3.0 pose a risk of back injury for most workers.

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Appendix B: Factors Comprising the Revised NIOSH Lifting Equation

Calculation for Recommended Weight Limit (RWL)

RWL = (LC) x (HM) x (VM) x (DM) x (AM) x (FM) x (CM)

	U.S. CUSTOMARY
LC = Load Constant	51 lbs
HM = Horizontal Multiplier	(10/H)
VM = Vertical Multiplier	(1-(0.0075|V-30|))
DM = Distance Multiplier	(0.82+(1.8/D))
AM = Asymmetric Multiplier	(1-(0.0032A))
FM = Frequency Multiplier	(from Table B1)
CM = Coupling Multiplier	(from Table B2)

Where:

H = Horizontal location of hands from midpoint between the ankles
Measured at the origin and the destination of the lift (inches)

V = Vertical location of the hands from the floor
Measured at the origin and destination of the lift (inches)

D = Vertical travel distance between the origin and the destination of the lift (inches)

A = Angle of asymmetry – angular displacement of the load from the sagittal plane
Measured at the origin and destination of the lift (°)

Duration is to be defined to be: ≤ 1 hour; ≤ 2 hours; ≤ 8 hours
Assuming appropriate recovery allowances

APPENDIX B: FACTORS COMPRISING THE REVISED NIOSH LIFTING EQUATION (CONTINUED)

Table B1. Frequency Multiplier (FM) for the Revised NIOSH Lifting Equation

Frequency Lifts/min	Work Duration					
	≤ 1 Hour		≤ 2 Hours		≤ 8 Hours	
	V < 30″	V ≥ 30″	V < 30″	V ≥ 30″	V < 30″	V ≥ 30″
0.2	1.00	1.00	0.95	0.95	0.85	0.85
0.5	0.97	0.97	0.92	0.92	0.81	0.81
1	0.94	0.94	0.88	0.88	0.75	0.75
2	0.91	0.91	0.84	0.84	0.65	0.65
3	0.88	0.88	0.79	0.79	0.55	0.55
4	0.84	0.84	0.72	0.72	0.45	0.45
5	0.80	0.80	0.60	0.60	0.35	0.35
6	0.75	0.75	0.50	0.50	0.27	0.27
7	0.70	0.70	0.42	0.42	0.22	0.22
8	0.60	0.60	0.35	0.35	0.18	0.18
9	0.52	0.52	0.30	0.30	0.00	0.15
10	0.45	0.45	0.26	0.26	0.00	0.13
11	0.41	0.41	0.00	0.23	0.00	0.00
12	0.37	0.37	0.00	0.21	0.00	0.00
13	0.00	0.34	0.00	0.00	0.00	0.00
14	0.00	0.31	0.00	0.00	0.00	0.00
15	0.00	0.28	0.00	0.00	0.00	0.00
>15	0.00	0.00	0.00	0.00	0.00	0.00

Table B2. Coupling Multiplier (CM) for the Revised NIOSH Lifting Equation

Couplings	Coupling Multipliers	
	V < 30″	V ≥ 30″
Good	1.00	1.00
Fair	0.95	1.00
Poor	0.90	0.90

Appendix C: Description of RNLE Evaluation of 712/713 Work Center

Following a cycle time analysis of one cylinder liner machining area, management combined the 712 and 713 areas into one work center. This resulted in two different castings being machined at the same time; all the machines are run by one worker. Figure C1 depicts the layout of the 712/713 work center during the site visit. Rough forged "Mexico" cylinder liners were retrieved from a pallet. The Mexico liner was milled on a series of machines then placed in a wire basket. The area is also capable of running "Lake City" cylinder liners; those are retrieved from a wire basket, and must be bored before proceeding through the same series of machines and then placed in a wire basket. Lifts performed during the current cycle time analysis are described in Table C1. Management also provided two proposed cycle time analyses that they were considering implementing. Proposal #1 had 32 total movements and 23 lifts (Table C2); proposal #2 had 32 total movements and 19 lifts (Table C3). When calculating the RNLE, three vertical locations were used: low pallet/cage, middle pallet/cage, and high pallet/cage. Measurements for each of the three locations were made during the site visit. It was assumed that when a cylinder liner was removed from the high pallet location, it would be placed in a low wire basket location, i.e., each full pallet required an empty wire basket.

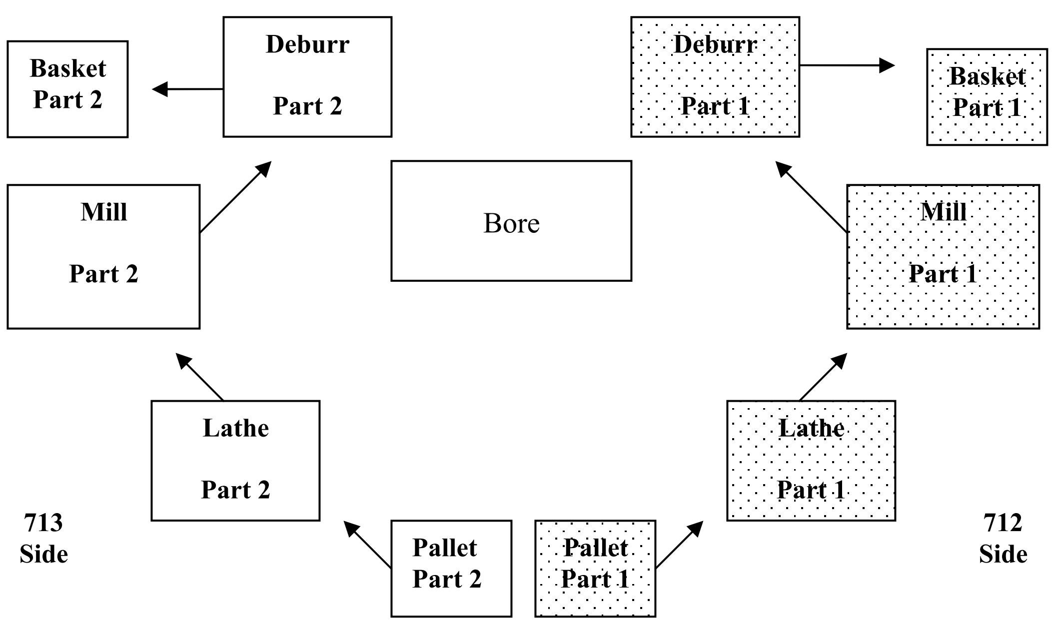

Figure C1. 712/713 Work center layout during NIOSH site visit.

Table C1. 712 and 713 *Current* Cycle Time Analysis

712 side Cycle #	712 side Task	713 side Cycle #	713 side Task
1	Castings to lathe table	14	Part to 713 lathe
2	Unload lathe	15	Unload lathe
3	Load lathe	16	Load lathe
4	Cycle start lathe	17	Cycle start lathe
5	Part to mill	18	Part to mill table
6	Unload mill to table	19	Unload mill
7	Load mill from table	20	Load mill
8	Cycle start mill	21	Cycle start mill
9	Milled part to deburr	22	Part to deburr table
10	Unload deburr	23	Unload deburr to finished
11	Load deburr	24	Walk to 712 castings
12	Cycle start deburr		17 lifts (highlighted)
13	Walk to 713 castings		Total man cycle time = 1.76 min/part

Table C2. 712 and 713 *Proposal #1* Cycle Time Analysis

712 side Cycle #	712 side Task	713 side Cycle #	713 side Task
1	Castings to bore	18	Part to 713 bore
2	Unload bore to both sides	19	Unload castings to both sides
3	Load bore both sides	20	Load both sides
4	Cycle start bore	21	Cycle start bore
5	Bore part to lathe	22	Bore part to lathe
6	Unload lathe	23	Unload lathe
7	Load lathe	24	Load lathe
8	Cycle start lathe	25	Cycle start lathe
9	Part to mill	26	Part to mill table
10	Unload mill to table	27	Unload mill
11	Load mill from table	28	Load mill
12	Cycle start mill	29	Cycle start mill
13	Milled part to deburr	30	Part to deburr table
14	Unload deburr	31	Unload deburr to finished
15	Load deburr	32	Walk to 712 castings
16	Cycle start deburr		23 lifts (highlighted)
17	Walk to 713 castings		Total man cycle time = 2.81 min/part

Table C3. 712 and 713 *Proposal #2* Cycle Time Analysis

712 side		713 side	
Cycle #	Task	Cycle #	Task
1	2 castings to bore	17	Walk to lathe
2	Unload bore to both sides	23	Unload lathe
3	Load bore both sides	24	Load lathe
4	Cycle start bore	25	Cycle start lathe
5	Bore parts to lathe	26	Part to mill table
6	Unload lathe	27	Unload mill
7	Load lathe	28	Load mill
8	Cycle start lathe	29	Cycle start mill
9	Part to mill	30	Part to deburr table
10	Unload mill to table	31	Unload deburr to finished
11	Load mill from table	32	Walk to castings
12	Cycle start mill		
13	Milled part to deburr		
14	Unload deburr		19 lifts (highlighted)
15	Load deburr		Total man cycle time = 2.24 min/part
16	Cycle start deburr		

Appendix D: Assumptions for Calculating CLI for the Current Cycle Time Analysis

Table D1. **Current** Cycle Time Analysis [low/empty pallet and high/full wire basket]

Lift #	1	2	3	5	6	7	9	10	11
W	11	11	11	11	11	11	11	11	11
H_o	20	12	12	12	12	12	12	12	12
V_o	22	47	30	30	40	30	30	36	30
H_d	12	12	12	12	12	12	12	12	12
V_d	30	30	47	30	30	40	30	30	36
A	0	0	0	0	0	0	0	0	0
C	fair	fair	fair	fair	fair	fair	fair	fair	fair
F	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Duration	8	8	8	8	8	8	8	8	8

Table D1. **Current** Cycle Time Analysis (continued)

Lift #	14	15	16	18	19	20	22	23
W	11	11	11	11	11	11	11	11
H_o	20	12	12	12	12	12	12	12
V_o	22	47	30	30	40	30	30	36
H_d	12	12	12	12	12	12	12	20
V_d	30	30	47	30	30	40	30	46
A	0	0	0	0	0	0	0	0
C	fair	fair	fair	fair	fair	fair	fair	fair
F	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Duration	8	8	8	8	8	8	8	8

Table D2. **Current** Cycle Time Analysis [middle pallet/middle wire basket]

Lift #	1	2	3	5	6	7	9	10	11
W	11	11	11	11	11	11	11	11	11
H_o	20	12	12	12	12	12	12	12	12
V_o	33	47	30	30	40	30	30	36	30
H_d	12	12	12	12	12	12	12	12	12
V_d	30	30	47	30	30	40	30	30	36
A	0	0	0	0	0	0	0	0	0
C	fair	fair	fair	fair	fair	fair	fair	fair	fair
F	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Duration	8	8	8	8	8	8	8	8	8

Table D2. **Current** Cycle Time Analysis (continued)

Lift #	14	15	16	18	19	20	22	23
W	11	11	11	11	11	11	11	11
H_o	20	12	12	12	12	12	12	12
V_o	33	47	30	30	40	30	30	36
H_d	12	12	12	12	12	12	12	20
V_d	30	30	47	30	30	40	30	33
A	0	0	0	0	0	0	0	0
C	fair	fair	fair	fair	fair	fair	fair	fair
F	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Duration	8	8	8	8	8	8	8	8

Table D3. **Current** Cycle Time Analysis [high/full pallet and low/empty wire basket]

Lift #	1	2	3	5	6	7	9	10	11
W	11	11	11	11	11	11	11	11	11
H_o	20	12	12	12	12	12	12	12	12
V_o	46	47	30	30	40	30	30	36	30
H_d	12	12	12	12	12	12	12	12	12
V_d	30	30	47	30	30	40	30	30	36
A	0	0	0	0	0	0	0	0	0
C	fair	fair	fair	fair	fair	fair	fair	fair	fair
F	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Duration	8	8	8	8	8	8	8	8	8

Table D3. **Current** Cycle Time Analysis (continued)

Lift #	14	15	16	18	19	20	22	23
W	11	11	11	11	11	11	11	11
H_o	20	12	12	12	12	12	12	12
V_o	46	47	30	30	40	30	30	36
H_d	12	12	12	12	12	12	12	20
V_d	30	30	47	30	30	40	30	22
A	0	0	0	0	0	0	0	0
C	fair	fair	fair	fair	fair	fair	fair	fair
F	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Duration	8	8	8	8	8	8	8	8

W = Weight lifted (pounds)
H_o = Horizontal height of lift at origin (inches)
V_o = Vertical height of lift at origin (inches)
H_d = Horizontal height of lift at destination (inches)
V_d = Vertical height of lift at destination (inches)
A = Asymmetry (degrees)
C = Coupling
F = Frequency (lifts per minute)

Acknowledgements and Availability of Report

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