CDC Workplace Safety and Health

Assessment of Physical Hazards at an Automobile Parts Manufacturing Facility

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Acknowledgements

Abbreviations

ACGIH®	American Conference of Governmental Industrial Hygienists
AL	Action level
bpm	(Heart) beats per minute
CBT	Core body temperature
dB	Decibels
dBA	Decibels, A-scale
ECF	Extracellular fluid
°F	Degrees Fahrenheit
HHE	Health hazard evaluation
Hz	Hertz
kg	Kilogram
kHz	Kilohertz
L	Liter
LEV	Local exhaust ventilation
mEq	Milliequivalent
mosm	Milliosmoles
NAICS	North American Industry Classification System
NIOSH	National Institute for Occupational Safety and Health
OEL	Occupational exposure limit
OSHA	Occupational Safety and Health Administration
PEL	Permissible exposure limit
ppm	Parts per million
REL	Recommended exposure limit
STEL	Short term exposure limit
TLV®	Threshold limit value
TWA	Time-weighted average
WBGT	Wet bulb globe temperature
WEEL	Workplace environmental exposure limit
WHO	World Health Organization

Highlights of the NIOSH Health Hazard Evaluation

The National Institute for Occupational Safety and Health (NIOSH) received a request from the United Autoworkers Union for a health hazard evaluation (HHE) at Tower Automotive in Bluffton, Ohio. NIOSH was asked to look at muscloskeletal and noise hazards throughout the production area, as well as heat stress in the paint department. NIOSH investigators conducted an initial survey in August 2003 and a heat stress evaluation in September 2004.

What NIOSH Did

- We conducted medical evaluations on colleagues participating in heat stress monitoring.
- We measured heat stress on the loaders and unloaders.
- We measured noise levels throughout the facility.
- We reviewed results of a noise survey and hearing tests done by contractors.
- We interviewed colleagues on their health and safety concerns.
- We reviewed Occupational Safety and Health Administration (OSHA) logs of illnesses and injuries.

What NIOSH Found

- There is potential for heat stress among the loaders and unloaders.
- The 70247 job posed an ergonomic hazard.
- Noise levels around the plant ranged from 85 to 100 decibels on an A-weighted scale.
- Between 2002 and 2003, the number of colleagues with normal hearing levels declined.
- The ventilation system built into a cut saw was not working.
- Housekeeping in the cut-saw area was poor.

What Tower Automotive Managers Can Do

- Allow colleagues to rest completely after loading or unloading parts.
- Position fans above the loader and unloader workstations.
- Relocate the bin used in the 70247 job in order to reduce stress on shoulders and wrists.
- Colleagues' noise levels should be tested periodically.
- Make sure that the ventilation system built in the cut saws is functioning.

What Tower Automotive Employees Can Do

- Drink plenty of fluids to keep yourself hydrated.
- Continue to properly wear hearing protection.
- Make sure work areas are kept clean.

Summary

On May 19, 2003, NIOSH received a union request to conduct an HHE at Tower Automotive in Bluffton, Ohio. The request stated that employees were subjected to highly repetitive work, loud metal stamping noise, and excessive heat in the painting department. The management referred to their employees as colleagues, so this term is used in this report.

During an initial site visit (August 21, 2003), NIOSH investigators reviewed documentation of past industrial hygiene and noise sampling and summaries of audiometric testing conducted at the facility, conducted noise sampling, performed an ergonomic evaluation of jobs that were in operation during our visit, and conducted confidential colleague interviews. During a follow-up site visit (September 13–16, 2004), personal exposure to heat stress and heat strain was assessed in the paint department.

Area monitors indicated that the temperature in the paint area was significantly higher than in a comparison area (cafeteria). Six colleagues provided 13 heat strain measures. Of the personal heat strain measures (core body temperature, heart rate, and skin temperature) collected in the paint department (fork lift operators, loaders and unloaders), six measures exceeded the ACGIH core body temperature lower limit (100.4°F), and one exceeded its upper limit (101.3°F). The average heart rate measures were 55–115 beats per minute, and the average skin temperatures ranged from 86°F to 98°F. Nine measures showed signs of dehydration, of which three reached or exceeded the 1.5% guideline for adequate hydration.

The ergonomic evaluation found that the 70247 press job presented an occupational hazard; relocation of the bin or other measures to reduce the amount of shoulder abduction and wrist flexion to retrieve parts should be a high priority for the company.

Noise levels in the facility were between 85 and 100 dBA. Colleagues were observed wearing hearing protectors consistently and properly. Normal hearing declined from 2002 to 2003.

On one of the cut-saw machines, the built-in LEV was not working. Metal shavings were observed all over the work area. During the confidential interviews, colleagues cited musculoskeletal injuries, heat stress from working in the paint department, and dust exposures as main concerns.

Loaders and unloaders in the paint department are at risk for excessive exposure to heat. To reduce heat strain, colleagues should be allowed to rest during the rest portion of the work/rest regiment, and not assigned any duties during this time. NIOSH investigators also identified an ergonomic hazard for the 70247 job evaluated during this survey. The hazard can be controlled by implementing measures to reduce the amount of shoulder abduction and wrist flexion to retrieve parts. Malfunction of the LEV system built into the cut-saw equipment can result in colleagues overexposed to particulate matter. By ensuring that the LEV systems work and keeping work areas clean will reduce exposures to particulates.

NIOSH investigators recommend that colleagues working in the paint department rest during the rest portion of the work/rest regiment, and not be assigned any duties during this time. Also, for colleagues performing the 70247 job, the amount of shoulder abduction and wrist flexion to retrieve parts should be reduced. One way to achieve this is by relocating the bin holding parts associated with this job. In the cut-saw area, make sure that the LEV systems function properly, and keep work areas clean.

Keywords: NAICS 336111 (Automobile manufacturing), heat stress, ergonomics, noise, particulates

INTRODUCTION

On May 19, 2003, NIOSH received a request from the United Auto Workers union to conduct an HHE at Tower Automotive in Bluffton, Ohio. The request stated that employees were subjected to highly repetitive work and loud metal stamping noise throughout the production area, and excessive heat in the paint department.

On August 21, 2003, NIOSH investigators conducted an initial site visit at Tower Automotive. An opening conference was held between NIOSH investigators, and management and union representatives. During the opening conference, it was noted that the company referred to their employees as colleagues. Therefore, this report uses this term to refer to employees at Tower Automotive. Following the opening conference, NIOSH investigators toured the facility with management and union representatives. During the tour, real-time noise measurements were taken with a Quest Electronics Model 2400 Sound Level Meter®.

Following the facility tour, NIOSH investigators reviewed documentation of past industrial hygiene sampling records, hearing tests, and noise sampling conducted at the facility; conducted noise sampling; performed an ergonomic evaluation of jobs that were in operation during our visit; and conducted confidential colleague interviews.

A follow-up site visit was conducted from September 13–16, 2004, to assess heat stress and heat strain in the paint department. Colleagues and managers were invited to a conference room where NIOSH investigators described the heat stress and heat strain evaluation.

Workplace Description

Tower Automotive was started in 1993 in Indiana. The company manufactures body structures, lower vehicle structures, suspension components, and modules for automotive manufacturers. Tower Automotive has a workforce of 12,000 in 60 countries.

The facility at Bluffton, Ohio, employs approximately 250 colleagues. They work 8 hours a day, 5 days a week. Colleagues work a variety of hours. In the paint area, the loaders work from 6:00 a.m. to 2:00 p.m. They take a 10-minute break at 8:00 a.m., and a 20-minute lunch break, at 11:00 a.m. By the nature of their job, the unloaders start a little later than the loaders, and stagger their shift relative to the loaders. They break for lunch at 11:35 a.m.

Process Description

Steel coils are decoiled through an automatic process and fed into a blanking press. In the blanking press, the coil is cut into flat shapes, called blanks. The blanks are deposited in containers, which are then moved by forklifts to the forming press to be fed into a form die. The formed parts fall down a chute to secondary operations such as painting.

At the two paint lines, loaders hang formed parts onto moving racks. The speed of racks is dependant upon the amount of time required to cure the parts. Parts are cleaned in a 5-stage washer, which leads into a dry-off oven. Following the dry-off oven, parts are conveyed into powder-coating booths that coat the parts with paint, then into a cure-oven that fastens the paint to the parts. Finally, the parts are allowed to cool before being manually removed from moving racks by unloaders. During the NIOSH site visit, only one of two paint lines was operational.

ASSESSMENT

Heat Stress and Heat Strain

WBGT measurements were collected using three QUESTemp36™ instruments (Quest Technologies, Inc., Oconomowoc, Wisconsin) to document the environmental conditions (temperature and relative humidity) during the heat strain monitoring. Two WBGT monitors were placed in the loading and unloading area among the colleagues while another monitor was placed in the cafeteria for comparison for the entire work shift. The monitors collected temperature data concurrently with the heat strain monitoring. More information on the WBGT monitors is presented in Appendix A.

Heat strain was measured on six colleagues, providing 13 measures over the 2-day evaluation. Heat strain was assessed using the CorTemp™ Wireless Core Body Temperature Monitoring System (HQ, Inc., Palmetto, Florida). Once swallowed, the CorTemp Temperature Sensor, a 0.9 x 0.4-inch silicon-coated electronic device, provides continuous monitoring of CBT to within ±0.2°F. Data is collected on a recorder that is attached to the wearer's belt. The study participants' CBTs were recorded at 1-minute intervals. Prior to administering the sensor, a NIOSH physician medically screened the study participants to insure that they were fit to participate in the use of this sensor (including listing medical conditions that make participation ineligible) before obtaining informed consent from the study participants. More information on the CorTemp sensor is provided in Appendix A.

Heat strain was also assessed using a Mini-Mitter Mini-Logger® Series 2000 (Mini-Mitter Company, Inc., Bend, Oregon). Heart rate and skin temperature were monitored at 1-minute intervals. The six study participants were asked to wear a Polar® chest band heart rate monitor during both days of the evaluation. The Polar chest band heart rate and skin temperature monitor counts up to 250 bpm and is accurate to within ±1 bpm.

Pre- and post-shift body weights were measured on all six colleagues on both days of the evaluation to determine their degree of dehydration. Weight loss (or gain) over a few hours is a reflection of change in extracellular fluid volume and occurs when water is lost from sweating and through the respiratory tract. Body weight loss of 1.5% or less indicates mild dehydration, whereas a loss of greater than 1.5% indicates a greater risk of heat stress. Study participants were weighed in uniform clothing near the beginning and end of the work shift with a self-calibrating electronic digital scale Model 812 (Measurement Specialties, Inc., Fairfield, New Jersey).

Ergonomics

The ergonomics evaluation consisted of a walk-through tour of the production area to observe the various operations as well as recording worker motions and movements on videotape. We talked to colleagues and floor supervisors to obtain information about job tasks.

Noise

Real-time noise measurements were collected with a Quest Technologies Model 2400 Sound Level Meter (Quest® Technologies, Oconomowoc, Wisconsin). The meter was calibrated according to manufacturer's instructions just before the facility tour and immediately after.

Colleague Interviews and Review of OSHA Logs

Eight Tower Automotive colleagues were identified by union representatives as individuals who had reported musculoskeletal injuries. These Tower Automotive colleagues were asked how long they worked for Tower Automotive, how long they worked in their current job, whether they had experienced any health effects they perceived as work related, and whether others in their work group had experienced work-related injuries or illnesses. In addition, OSHA 200/300 logs of illness and injury from 2001–2003 were also reviewed. Information on the OELs and health effects for heat stress and heat strain, ergonomics, and noise, are provided in Appendix B.

Results and Discussion

Heat Stress and Heat Strain

The heat stress/strain evaluation was carried out under atypical conditions because the summer of 2004 was unseasonably mild. In addition, during the NIOSH site visit the line that usually runs the heavy parts was not functioning. Thus some heavy parts were run along with the light parts, underestimating the heavy workload that may otherwise occur at this facility. Despite the cooler temperatures and lighter workloads, four colleagues (2 loaders and 2 unloaders) exceeded the ACGIH CBT's lower limit (100.4°F) six times, and one colleague exceeded its upper limit (101.3°F) once. Physical exertion from loading and unloading the various parts in close proximity to the oven explains the CBT excursions above the ACGIH limits. The lower limit CBT excursions should serve as a warning that the workers need to drink more fluids, and rest in a cool place. Table 1 summarizes the CBT, heart rate, and skin temperature data for all study participants, and Table 2 shows percent of time that study participants exceeded CBT and skin temperature.

Table 1. Summary data (range) for heat strain parameters

Job title	n	Core body temperature (°F)	Heart rate (beats per minute)	Skin temperature (°F)
Loaders	4	98.3–102.0	99–115	89.3–96. 7
Unloaders	6	98.3–101.0	66–103	85.8–93.6
Forklift operator	3	98.1–100.1	55–79	91.1–97.6

Table 2. Percent of time that employees exceeded lower and upper limits for core body and skin temperatures

Employee ID		Core body temperature		Skin temperature	
		Lower limit	Upper limit	Lower limit	Upper limit
Day 1	A	0	0	0	0
	B	23	0	3	0
	C	0	0	62	0
	D	100	63	0	0
Day 2	A	0	0	0	0
	B	0	0	53	0
	C	0	0	0	0
	D	17	0	0	0
Day 3	A	0	0	0	0
	C	10	0	0	0
	D	9	0	5	0
	E	55	0	0	0
	F	0	0	0	0

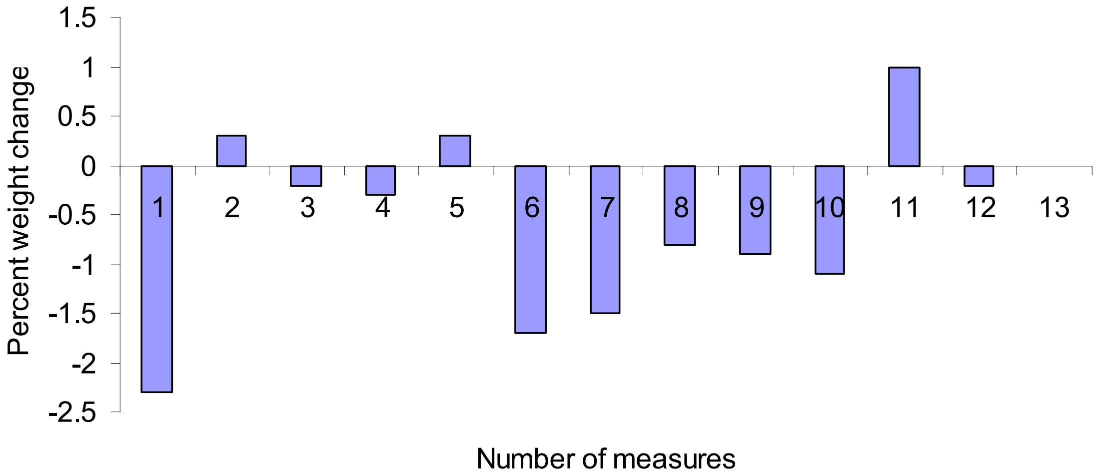
Some of the equipment running on electricity interfered with the functioning of the CBT recorder. These data points were easily identified upon downloading the data and were eliminated from further analysis. On the third day, the skin temperature and heart rate measurement for one study participant showed erroneous results because the sensors were not making proper contact with the participant's body. Table 3 denotes the percentage of points that were eliminated from the study for CBT, heart rate, and skin temperature.

Table 3. Median (and range) percentages of data that was discarded due to electronic interferences

Heat strain parameters	Day 1	Day 2	Day 3
Core body temperature	27 (24–30%)	17 (0–51%)	4 (1–16%)
Heart rate	0	0	0 (0–51%)
Skin temperature	0	0	0 (0–3%)

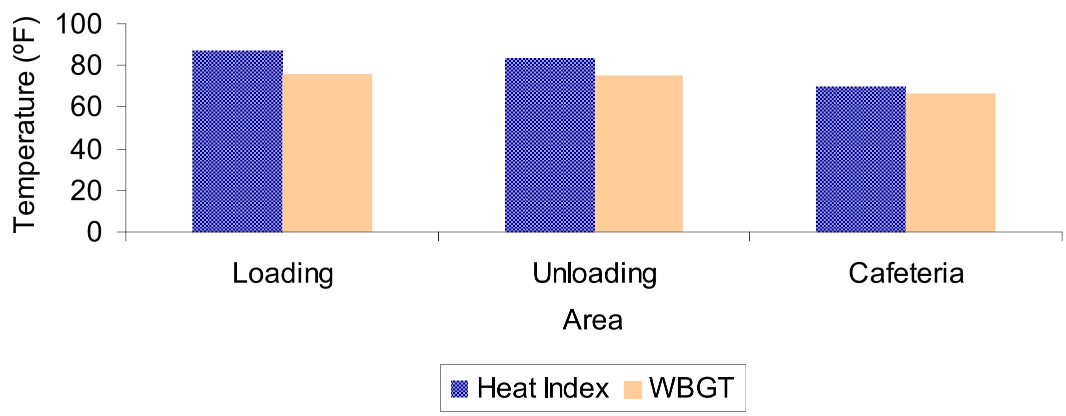
An indication of heat stress is excessive loss of body weight (more than 1.5%) over the course of a work shift. Of the 13 measures in this study, nine showed signs of dehydration (post-weight was less than pre-weight); of these, three met or exceeded the 1.5% guideline for adequate hydration (Figure 1).

Figure 1. Percent weight change over work shift



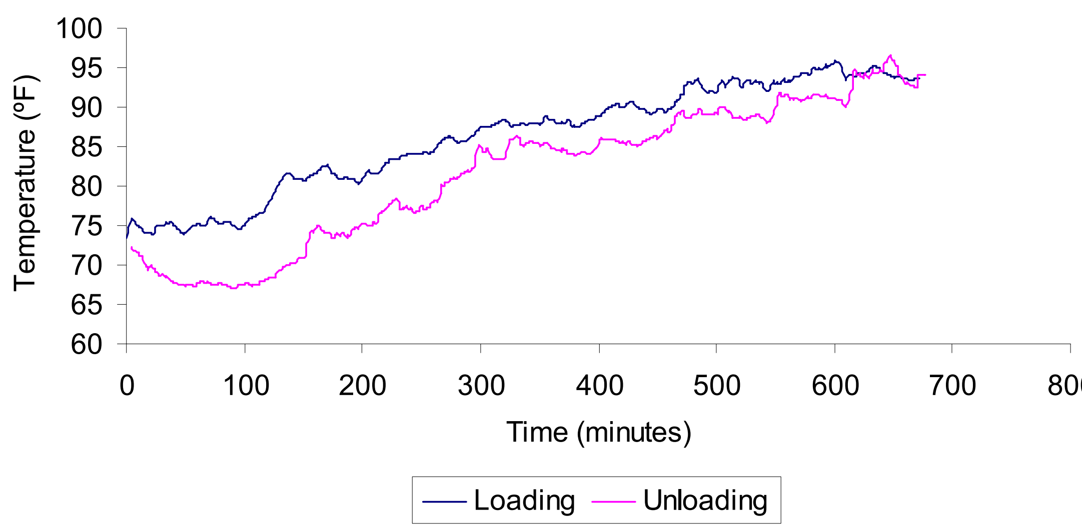
The WBGT data show that the loader area had higher temperatures than the unloader area, though the mean differences were not statistically significant using a paired *t*-test for means. The dry bulb temperature range was between 80.5°F and 86.2°F for the loading and unloading areas, and 70.2°F–70.7°F for the cafeteria. When the loader and unloader area measurements were compared to measurements from a monitor set up in the cafeteria, the mean temperature differences were statistically significant ($p < 0.05$). Figure 2 compares the WBGT measurements in the loading area, unloading area, and the cafeteria.

Figure 2. Comparison of heat index and WBGT measurements during loading and unloading



The temperature in the loading and unloading areas increased steadily throughout the day (Figure 3), suggesting inadequate ventilation. The temperature in the unloading area was slightly lower than the temperature in the loading area, which is possibly due to the loading area being closer to the oven than the unloading area.

Figure 3. Profile of dry temperature measurements in loading and unloading areas



Management had a proactive approach to reducing heat stress in the work place. Administrative measures in place included having colleagues start the day as early as 6:00 a.m. and completing their workday by 2:00 p.m. Water was available for colleagues in the vicinity of the work area. A work/rest regimen was established whereby a colleague takes a break after loading and unloading parts for a certain length of time. The work/rest ratio depended upon the size of the part. For light parts (less than 5 pounds), the colleagues did not rotate. However, for parts that weighed 14–20 pounds (radius arms and moonbeams), the work/rest ratio was 2:1. For example, when working with the radius arms, colleagues worked for 16 minutes and rested for 8 minutes. An air-conditioned room near the loading and unloading lines was available to the colleagues for their breaks. However, we observed colleagues being reassigned to other jobs such as sweeping and mopping when they were on the rest portion of the work/rest regimen. A heat stress training program is provided to colleagues on an annual basis. Each of the lines had fans on them to cool the colleagues; however, the position of the fans was such that they blew hot air directly onto the colleagues. Positioning the fan above the colleagues' heads would minimize the amount of hot air blown directly on them.

Two compressors were located directly behind the loaders. During this evaluation, one of the compressors was in use. This compressor had a plastic curtain around it to contain the heat. A vent was placed above the compressor to remove the hot air. However, the vent was not directly above the path of the hot air so part of the hot air eventually escaped to the loaders. Also, if both compressors were running simultaneously, radiant heat may affect the loaders by increasing the surrounding temperature.

A limitation of the heat stress evaluation was low colleague participation. Only a third of eligible colleagues volunteered to participate. The 13 measures in this study represented repeat measures from six study participants over 2 days. The study may have been more generalizable had more colleagues volunteered for the study; the results from this evaluation are not representative. Some of the reported reasons for not participating included discomfort at swallowing the CBT sensor and fear of reprisal from management if they were to participate in the study.

Ergonomics

Most of the jobs with potential ergonomic problems were found in welding, press, or painting operations. In general, the input and output bins were located within the convenient reach of the colleagues. This was accomplished by extensive use of tilt stands and bins with drop down sides. NIOSH investigators videotaped short sequences of several jobs for subsequent analysis to document the presence of risk factors associated with the development of upper extremity musculoskeletal disorders. The jobs were selected mainly to illustrate the various methods that parts are delivered to and retrieved from colleagues. The jobs videotaped were loading and unloading parts in the paint department, welding job 5222, upper control arm assembly, a control arm press job, and press operations 70247 and 70425. Jobs that required stacking parts after the operation could not have tilted bins, although these input and output bins did have drop-down sides. These jobs often required precision placement of the parts and some reaching, but not outside the reach envelope of the colleague. Finished parts from one welding job (5222) were stacked in a wooden box specified by the vendor and did not have a drop-down side or tilt table. As such, the colleague had to reach over the side of the bin to stack the parts. During painting operations, colleagues removed parts from hooks as the parts went by and tossed them into metal bins. None of the assembly jobs observed appeared to be highly repetitive, and colleagues were able to keep up with the pace of the machine without difficulty.

The 70247 press job, where a bushing and a washer are added to a small suspension part, had an input bin that required the colleague to reach beyond a comfortable distance. The 3-foot tall metal bin with a drop-down side situated on a tilt stand was similar to other metal bins in the facility. The leading edge of the bin was approximately 2 feet above floor level. The parts were not stacked, but they were small, which prevented the side from being dropped until the bin was about half empty. This required the colleague to reach above shoulder height and into the bin to retrieve the parts. The bin holds approximately 2000 parts and would take more than one day to empty (1500–1800 parts used per day).

Noise

Area noise measurements were collected during the walk-through tour. Generally, noise levels were measured between 90 and 100 dBA in areas where machines were in operation. In the shipping/receiving and maintenance areas where there were no operating machines, noise levels were approximately 85 dBA. No Tower Automotive colleagues were observed without hearing protection devices while they were on the shop floor. A few were seen wearing ear muffs, but the vast majority wore foam earplugs. The earplugs were observed to be worn correctly (deeply inserted), and several hearing protection device dispensers were noted throughout the facility.

A facility-wide noise dosimeter survey had been performed by an outside contractor for Tower Automotive in 2002. The results of that survey were furnished to NIOSH investigators for review. The consultant reported that most of the 8-hour TWA noise levels exceeded the OSHA AL stipulated in the hearing conservation amendment [29 CFR 1910.95]. Additionally, nearly all of the measurements also exceeded the PEL of 90 dBA, using a 5-dB exchange rate. Because of these noise findings, Tower Automotive contracted with an audiometric test provider to administer hearing tests to their colleagues according to the OSHA hearing conservation amendment. The contractor is a member of the National Hearing Conservation Association and meets the association's code of ethics for this type of provider. Audiometric test data for 2002 and 2003 were reviewed by a NIOSH investigator. According to the contractor's summary report, normal hearing was measured in 86% of the 304 colleagues tested in 2002, while 74% of 293 tested colleagues were found to have normal hearing in 2003. Tower Automotive should continue to scrutinize the hearing test results to determine if this decline in the number of colleagues with normal hearing continues.

Colleague Interviews and Review of OSHA logs

The general health concerns reported during the confidential interviews included work arrangements that were not ergonomically compatible with the worker, musculoskeletal injuries, heat stress from working in the painting operation, and a lack of available respiratory protection for colleagues involved in dust-generating procedures. In 2001, 12 of 48 (25%) OSHA recordable injuries were attributed to arm, wrist, back, foot, and shoulder strain. In 2002, the number of recordable injuries dropped to 24, and the number of strains was down to 5. In 2003,

Results and Discussion (continued)

the number of recordable injuries dropped further, to 18, with the number of strains down to 3. Almost all of the strains occurred in the stamping and paint departments.

Particulate Matter

Based on concerns from a colleague, a NIOSH investigator examined the cut-saw area for potential exposure to particulate matter. The cut-saw equipment is used to cut metal pieces to the desired shape and size. The equipment is designed to capture metal shavings via a built-in LEV system. However, on one of the machines, the LEV was not functioning, and metal shavings were found on the floor and the work surface.

Conclusions

Colleagues exceeded the lower limit for CBT six times and the upper limit once, indicating a potential for heat stress at this facility. This survey shows that WBGT measurements alone are not adequate to describe heat stress on employees. For the 70247 press job, relocation of the bin or other measures to reduce the amount of shoulder abduction and wrist flexion to retrieve parts should be a high priority for the company. Tower Automotive should continue to periodically measure colleagues' occupational noise exposures. The 3-year cycle recommended by the contractor should be sufficient unless changes are made that could affect noise exposure. If the LEV system that is built into the cut-saw equipment malfunctions, colleagues may be exposed to particulate matter and metal shavings in the cut-saw area.

Recommendations

Heat Stress and Heat Strain

Although the company has taken a proactive stance in reducing heat stress, the following steps may further reduce the potential for heat stress:

- Allow colleagues to rest during the rest portion of the work/rest regiment, and not assign any duties during this time.
- Position fans above workstations, not directly in front of the colleagues.
- Hire a consultant familiar with ventilation in hot processes to reduce heat.

Recommendations (continued)

Ergonomics

For the 70247 press job, lower the tilt stand so that the leading edge of the metal bin is closer to floor level. An easier approach would be to continue using the tilt stand, but only fill the bin to the level of the drop-down side. This would locate the parts closer to waist level and relieve the colleagues of awkward, stressful shoulder and wrist postures. The output bin for this operation is located conveniently for the colleagues.

Noise

A new noise survey should be conducted if changes are made that can affect noise exposures. The audiometric testing of colleagues should also continue on an annual basis. The reduction in percent of colleagues with normal hearing should be tracked to make sure that the reduction does not continue. If the number of colleagues with normal hearing falls again in the next round of hearing tests, Tower Automotive should retrain their colleagues on the effects of noise on hearing and how to protect themselves from these effects, and also determine if new types of hearing protection devices are necessary to further reduce noise exposure until engineering controls to lower the production noise process are identified and implemented.

Particulate Matter

If the LEV system that is built into the cut-saw equipment malfunctions, colleagues may be exposed to particulate matter and metal shavings in the cut-saw area. Ensuring that the LEV systems work and keeping the work areas clean will reduce colleagues' exposures to particulates.

Reference

CFR. Code of Federal Regulations. Washington, DC: U.S. Government Printing Office, Office of the Federal Register.

Appendix A: Methods

The WBGT monitors are capable of measuring temperatures of 23°F–212°F and are accurate to within ±0.9°F. In addition to temperature, the monitors are capable of measuring relative humidities of 0%–100% and are accurate to within ±5%. The WBGT index accounts for air velocity, temperature, humidity, and radiant heat and is a useful index of the environmental contribution to heat stress. It is a function of dry bulb temperature (a standard measure of air temperature taken with a thermometer), natural wet bulb temperature (simulates the effects of evaporative cooling), and black globe temperature (estimates radiant [infrared] heat load).

The CorTemp sensor passes through the gastrointestinal tract and exits the body in an average of approximately 72 hours. The sensor, intended for one-time use only, runs on a non-rechargeable silver oxide battery and utilizes a temperature-sensitive crystal that vibrates in direct proportion to the temperature of the substance surrounding it. This vibration creates an electromagnetic flux (frequency = 262.144 kHz) that continuously transmits out of the body. A recorder receives this signal and translates it into digital temperature information, which is then displayed on the unit and stored to memory. The recorder monitors temperatures of 50°F–122°F. The recorder operates on one standard 9-volt alkaline battery, weighs about 7 ounces, and attaches to the user's belt.

Appendix B: Occupational Exposure Limits and Health Effects

In evaluating the hazards posed by workplace exposures, NIOSH investigators use both mandatory (legally enforceable) and recommended OELs for chemical, physical, and biological agents as a guide for making recommendations. OELs have been developed by Federal agencies and safety and health organizations to prevent the occurrence of adverse health effects from workplace exposures. Generally, OELs suggest levels of exposure to which most workers may be exposed up to 10 hours per day, 40 hours per week for a working lifetime without experiencing adverse health effects. However, not all workers will be protected from adverse health effects even if their exposures are maintained below these levels. A small percentage may experience adverse health effects because of individual susceptibility, a pre-existing medical condition, and/or a hypersensitivity (allergy). In addition, some hazardous substances may act in combination with other workplace exposures, the general environment, or with medications or personal habits of the worker to produce health effects even if the occupational exposures are controlled at the level set by the exposure limit. Also, some substances can be absorbed by direct contact with the skin and mucous membranes in addition to being inhaled, which contributes to the individual's overall exposure.

Most OELs are expressed as a TWA exposure. A TWA refers to the average exposure during a normal 8- to 10-hour workday. Some chemical substances and physical agents have recommended STEL or ceiling values where health effects are caused by exposures over a short period. Unless otherwise noted, the STEL is a 15-minute TWA exposure that should not be exceeded at any time during a workday, and the ceiling limit is an exposure that should not be exceeded at any time.

In the U.S., OELs have been established by Federal agencies, professional organizations, state and local governments, and other entities. Some OELs are legally enforceable limits, while others are recommendations. The U.S. Department of Labor OSHA PELs (29 CFR 1910 [general industry]; 29 CFR 1926 [construction industry]; and 29 CFR 1917 [maritime industry]) are legal limits enforceable in workplaces covered under the Occupational Safety and Health Act. NIOSH RELs are recommendations based on a critical review of the scientific and technical information available on a given hazard and the adequacy of methods to identify and control the hazard. NIOSH RELs can be found in the *NIOSH Pocket Guide to Chemical Hazards* [NIOSH 2005]. NIOSH also recommends different types of risk management practices (e.g., engineering controls, safe work practices, worker education/training, personal protective equipment, and exposure and medical monitoring) to minimize the risk of exposure and adverse health effects from these hazards. Other OELs that are commonly used and cited in the U.S. include the TLVs recommended by ACGIH, a professional organization, and the WEELs recommended by the American Industrial Hygiene Association, another professional organization. The TLVs and WEELs are developed by committee members of these associations from a review of the published, peer-reviewed literature. They are not consensus standards. ACGIH TLVs are considered voluntary exposure guidelines for use by industrial hygienists and others trained in this discipline "to assist in the control of health hazards" [ACGIH 2007]. WEELs have been established for some chemicals "when no other legal or authoritative limits exist" [AIHA 2007].

Outside the U.S., OELs have been established by various agencies and organizations and include both legal and recommended limits. Since 2006, the Berufsgenossenschaftliches Institut für Arbeitsschutz (German Institute for Occupational Safety and Health) has maintained a database of international OELs from European Union member states, Canada (Québec), Japan, Switzerland, and the U.S. [http://www.hvbg.de/e/bia/gestis/limit_values/index.html]. The database contains international limits for over 1250 hazardous substances and is updated annually.

Employers should understand that not all hazardous chemicals have specific OSHA PELs, and for some agents the legally enforceable and recommended limits may not reflect current health-based information. However, an employer is still required by OSHA to protect its employees from hazards even in the absence of a specific OSHA PEL. OSHA requires an employer to furnish employees a place of employment free from recognized hazards that cause or are likely to cause death or serious physical harm [Occupational Safety and Health Act of 1970 (Public Law 91–596, sec. 5(a)(1))]. Thus, NIOSH investigators encourage employers to make use of other OELs when making risk assessment and risk management decisions to best protect the health of their employees. NIOSH investigators also encourage the use of the traditional hierarchy of controls approach to eliminate or minimize identified workplace hazards. This includes, in order of preference, the use of: (1) substitution or elimination of the hazardous agent, (2) engineering controls (e.g., local exhaust ventilation, process enclosure, dilution ventilation), (3) administrative controls (e.g., limiting time of exposure, employee training, work practice changes, medical surveillance), and (4) personal protective equipment (e.g., respiratory protection, gloves, eye protection, hearing protection). Control banding, a qualitative risk assessment and risk management tool, is a complementary approach to protecting worker health that focuses resources on exposure controls by describing how a risk needs to be managed [http://www.cdc.gov/niosh/topics/ctrlbanding/]. This approach can be applied in situations where OELs have not been established or can be used to supplement the OELs, when available.

Heat Stress and Heat Strain

NIOSH defines heat stress exposure as the sum of the heat generated in the body (metabolic heat) plus the heat gained from the environment (environmental heat) minus the heat lost from the body to the environment, primarily through evaporation. Many bodily responses to heat stress are desirable and beneficial because they help regulate internal temperature and, in situations of appropriate repeated exposure, help the body adapt (acclimatize) to the work environment. However, at some stage of heat stress, the body's compensatory measures cannot maintain internal body temperature at the level required for normal functioning. As a result, the risk of heat-induced illnesses, disorders, and accidents substantially increases. Increases in unsafe behavior are also seen as the level of physical work of the job increases [NIOSH 1986].

Many heat stress guidelines have been developed to protect people against heat-related illnesses. The objective of any heat stress index is to prevent a person's CBT from rising excessively. The WHO concluded that, "it is inadvisable for CBT to exceed 100.4°F or for oral temperature to exceed 99.5°F in prolonged daily exposure to heavy work and/or heat" [WHO 1969]. According to NIOSH, a CBT of 102.2°F should be considered reason to terminate exposure even when CBT is being monitored. This does not mean that a worker with a CBT exceeding those levels will necessarily experience adverse health effects; however, the number of unsafe acts increases as does the risk of developing heat stress illnesses [NIOSH 1986].

ACGIH guidelines require the use of a decision-making process that provides step-by-step situation-dependent instructions that factor in clothing insulation values and physiological evaluation of heat strain [ACGIH 2006]. ACGIH WBGT screening criteria factor in the ability of the body to cool itself (clothing insulation value, humidity, and wind) and, like the NIOSH criteria, can be used to develop work/rest regimens for acclimatized and unacclimatized employees. The ACGIH WBGT-based heat exposure assessment was developed for a traditional work uniform of long-sleeved shirt and pants, and represents conditions under which it is believed that nearly all adequately hydrated, unmedicated, healthy workers, may be repeatedly exposed without adverse health effects. Clothing insulation values and the appropriate WBGT adjustments, as well as descriptors of the other decision-making process components can be found in ACGIH's *Documentation of the Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices* [ACGIH 2006]. The ACGIH TLV for heat stress attempts to provide a framework for the control of heat-related illnesses only. Although accidents and injuries can increase with increasing levels of heat stress, it is important to note that the TLVs are not directed toward controlling these [ACGIH 2006].

NIOSH and ACGIH criteria can only be used when WBGT data for the immediate work area are available and must not be used when workers wear encapsulating suits or garments that are impermeable or highly resistant to water vapor or air movement. Further assumptions regarding work demands include an 8-hour work day, 5-day work week, two 15-minute breaks, and a 30-minute lunch break, with rest area temperatures the same as, or less than, those in work areas, and at least some air movement. It must be stressed that NIOSH and ACGIH guidelines do not establish a fine line between safe and dangerous levels but require professional judgment and a heat stress management program to ensure protection in each situation. The OSHA technical manual's section on heat stress refers back to the ACGIH document for guidelines to evaluate employee heat stress and how to investigate the workplace [OSHA 1999].

The body's response to heat stress is called heat strain [NIOSH 1986; ACGIH 2006]. Operations involving high air temperatures, radiant heat sources, high humidity, direct physical contact with hot objects, and strenuous physical activities have a high potential for inducing heat strain in employees. Heat strain is highly individual and cannot be predicted based upon environmental heat stress measurements. Physiological monitoring for heat strain becomes necessary when impermeable clothing is worn, when heat stress screening criteria are exceeded, or when data from a detailed analysis (such as the International Standards Organization-required sweat rate) shows excess heat stress.

One indicator of physiological strain, sustained peak heart rate, is considered by ACGIH to be the best sign of acute, high-level exposure to heat stress. Sustained peak heart rate, defined by ACGIH as 180 bpm minus an individual's age, is a leading indicator that thermal regulatory control may not be adequate and that increases in CBTs have, or will soon, occur. Sustained peak heart rate represents an equivalent cardiovascular demand of about 75% of maximum aerobic capacity. During an 8-hour work shift, although sustained peak demands may not occur, excessive demand may still be placed on the cardiovascular system. These "chronic" demands can be measured by calculating the average heart rate over the shift [ACGIH 2006]. A study of Marine Corps recruits revealed that decreases in physical job performance were observed when the average heart rate exceeded 115 bpm over the entire shift. This level is equivalent to working at roughly 35% of maximum aerobic capacity, a level sustainable for 8 hours [Minard 1961].

According to ACGIH, an individual's heat stress exposure should be discontinued when *any* of the following excessive heat strain indicators occur:

- Sustained (over several minutes) heart rate exceeds 180 bpm minus the individual's age in years, for those with normal cardiac performance
- CBT is greater than 100.4°F for unselected, unacclimatized personnel and greater than 101.3°F for medically fit, heat-acclimatized personnel
- Recovery heart rate at 1-minute after a peak work effort exceeds 110 bpm
- There are symptoms of sudden and severe fatigue, nausea, dizziness, or lightheadedness

An individual may be at greater risk of heat strain if:

- Profuse sweating is sustained over several hours
- Weight loss over a shift is greater than 1.5% of body weight
- 24-hour urinary sodium excretion is less than 55 millimoles

Health Effects of Exposure to Hot Environments

Heat disorders and health effects of individuals exposed to hot working environments include (in increasing order of severity) skin disorders (heat rash, hives, etc.), heat syncope (fainting), heat cramps, heat exhaustion, and heat stroke. Heat syncope (fainting) results from blood flow being directed to the skin for cooling, resulting in decreased supply to the brain, and most often strikes workers who stand in place for extended periods in hot environments. Heat cramps, caused by sodium depletion due to sweating, typically occur in the muscles employed in strenuous work. Heat cramps and syncope often accompany heat exhaustion, or weakness, fatigue, confusion, nausea, and other symptoms. Dehydration, sodium loss, and elevated CBT (above 100.4°F) are usually due to individuals performing strenuous work in hot conditions with inadequate water and electrolyte intake. Heat exhaustion may lead to heat stroke if the patient is not quickly cooled and rehydrated.

While heat exhaustion victims continue to sweat as their bodies struggle to stay cool, heat stroke victims cease to sweat as their bodies fail to maintain an appropriate core temperature. Heat stroke occurs when hard work, hot environment, and dehydration overload the body's capacity to cool itself. This thermal regulatory failure (heat stroke) is a life-threatening emergency requiring immediate medical attention. Signs and symptoms include irritability, confusion, nausea, convulsions or unconsciousness, hot dry skin, and a CBT above 106°F. Death can result from damage to the brain, heart, liver, or kidneys [Cohen 1990].

Prolonged increases in CBT and chronic exposures to high levels of heat stress are associated with disorders such as temporary infertility (male and female), elevated heart rate, sleep disturbance, fatigue, and irritability. During the first trimester of pregnancy, a sustained CBT greater than 102.2°F may endanger the fetus [ACGIH 2006]. In addition, one or more occurrences of heat-induced illness in a person predisposes him/her to subsequent injuries and can result in temporary or permanent loss of that person's ability to tolerate heat stress [NIOSH 1986; OSHA 1999].

The level of heat stress at which health effects occur is highly individual and depends upon the heat tolerance capabilities of each individual. Age, weight, degree of physical fitness, degree of acclimatization, metabolism, use of alcohol or illicit drugs, over the counter and prescribed medications, and a variety of medical conditions, such as hypertension and diabetes, all affect a person's sensitivity to heat. At greatest risk are unacclimatized workers, people performing physically strenuous work, those with previous heat illnesses, the elderly, people with cardiovascular or circulatory disorders (diabetes, atherosclerotic vascular disease), those taking medications that impair the body's cooling mechanisms, people who use alcohol or are recovering from recent use, people in poor physical condition, and those recovering from illness. With regard to prescribed medications, ß-adrenergic receptor blockers and calcium-channel blockers, used to treat hypertension, limit maximal cardiac output and alter normal vascular distribution of blood flow in response to heat exposure. Diuretics, such as caffeine, can limit cardiac output and affect heat tolerance and sweating; antihistamines, phenothiazines, and cyclic antidepressants can impair sweating [NIOSH 1986]. A CBT increase of only 1.8°F above normal encroaches on the brain's ability to function [ACGIH 2006].

Acclimatization

When workers are first exposed to a hot environment, they show signs of distress and discomfort, experience increased CBTs and heart rates, and may have headaches and/or nausea. On repeated exposure there is marked adaptation to the hot environment known as acclimatization. Acclimatization is the process that allows the body to begin sweating sooner and more efficiently, reduces electrolyte concentrations in the sweat, and allows the circulation to stabilize so that the worker can withstand greater amounts of heat stress while experiencing reduced heat strain signs and symptoms.

Acclimatization begins with consecutive exposures to working conditions for 2 hours at a time, with a requisite rise in metabolic rate. This will cause the body to reach 33% of optimum acclimatization by the fourth day of exposure. Cardiovascular function will stabilize, and surface and internal body temperatures will be lower by day 8 when the body has reached 44% of optimum acclimatization. A decrease in sweat and urine electrolyte concentrations are seen at 65% of optimum (day 10); 93% of optimum is reached by day 18 and 99% by day 21 [ACGIH 2006].

The loss of acclimatization begins when the activity under those heat stress conditions is discontinued, and a noticeable loss occurs after 4 days. This loss is usually rapidly recovered so that by Tuesday workers who were off on the weekend are as well acclimatized as they were on the preceding Friday. Chronic illness, an acute episode of mild illness (e.g., gastroenteritis), the use or misuse of pharmacologic agents, a sleep deficit, a suboptimal nutritional state, or a disturbed water and electrolyte balance may reduce the worker's capacity to acclimatize [ACGIH 2006].

Dehydration and Hyponatremia

When working in hot environments it is often difficult to completely replace lost fluids as the day's work proceeds. High sweat rates with excessive loss of body fluids may result in dehydration and electrolyte imbalances [Bates et al. 1996]. Some studies have shown that even small deficits adversely affect performance [Sawka and Neufer 1993]. Dehydration also negates the advantage granted by high levels of aerobic fitness and heat acclimatization [Ekblom et al. 1970].

Several studies have shown that dehydration increases CBT during exercise in temperate and hot environments; a deficit of only 1% of body weight increases CBT during exercise. As the magnitude of the water deficit increases, there is an accompanying elevation in CBT when exercising in the heat. The magnitude of this elevation ranges from 0.2°F–0.4°F for every 1% body weight loss [Sawka et al. 1979]. A 2% loss of body weight is generally accepted as the threshold for thirst stimulation [Szlyk et al. 1989]. A 3% decrease in body weight causes an increase in heart rate, depressed sweating sensitivity, and a substantial decrease in physical work capacity [Candas et al. 1986]. Some investigators have reported that a 4%–6% water deficit has been associated with anorexia, impatience, and headache, while a 6%–10% deficit is associated with vertigo, shortness of breath, cyanosis, and spasticity. With a 12% water deficit, an individual will be unable to swallow and will need assistance with rehydration. Lethal dehydration levels are estimated to occur at 15%–25% lost body weight.

Because water is the most abundant constituent in the body, comprising approximately 60% of the body weight in men and 50% in women, maintaining enough water improves the body's overall function. Total body water is distributed in two major compartments: 55%–75% is intracellular fluid and 25%–45% is ECF [Singer and Brenner 1998]. The solute, or dissolved particle concentration of a fluid, is known as its osmolality expressed as mosm/L. The major ECF component is sodium (Na^+); therefore, ECF volume is a reflection of total body sodium content.

Normal plasma osmolality ranges from 275–290 mosm/L and is kept within a narrow range by mechanisms capable of sensing a 1%–2% change in plasma concentration. Most people have an obligate water loss consisting of urine, stool, and evaporation from the skin and respiratory tract. In order to maintain a steady state, water intake must equal water excretion. Disorders of water regulation result in hyponatremia or hypernatremia. Changes in urine and plasma osmolality are better suited for diagnosing hydration status than changes in hematocrit, serum protein, and blood urea nitrogen, which are more dependent on factors other than hydration [NIOSH 1986; Wallach 2000]. The primary stimulus for water ingestion is thirst, which can be triggered by the following physiological mechanisms: an increase in osmolality, a decrease in ECF volume, or a decrease in blood pressure. Osmoreceptors in the hypothalamus are stimulated by a rise in serum concentration. The average osmotic threshold for thirst is approximately 295 mosm/kg and varies among individuals. Under normal circumstances, daily water intake exceeds physiological requirements [Rolls 1993].

Dehydration is not the only factor in heat stress, there is also the matter of electrolyte depletion. Sodium, a vital electrolyte, is excreted as the body sweats in order to utilize evaporative cooling. Two of the many functions of sodium in the body are to conduct impulses along neurons and maintain concentration gradients in the kidney for proper urine production.

Most individuals with acute exercise-induced heat disorder are dehydrated with normal to mildly increased serum sodium and serum osmolality (hypernatremia). Hyponatremia develops when serum sodium levels drop below 135 mEq/L and is a life-threatening condition that has been recognized as a potential health consequence of endurance activities conducted in hot environments. Increased water intake prior to and during activities in hot environments is highly emphasized to prevent dehydration and heat illness. However, drinking too much water can lead to decreased serum sodium concentrations (water toxicity or hyponatremia), and has been recognized as an increasing problem among U.S. military recruits [Gardner 2002].

Hyponatremia may occur with hypo-, hyper-, or normal hydration status [Roetzheim 1991]. Symptomatic and potentially life-threating hyponatremia can occur when blood sodium concentrations decrease to less than 130 mEq/L and is generally caused by hypervolemia (water overload) secondary to extensive over-drinking. Many people with hyponatremia have increased their total body water by about 1 gallon to achieve such low serum sodium values [Montain et al. 1999].

Most cases of hyponatremia result from the inability of the kidneys to excrete an appropriately dilute urine. The most significant clinical signs of hyponatremia involve the central nervous system, and symptoms vary from subtle changes in one's ability to think, to decreases in energy levels, and to severe alterations, such as coma or seizure. Symptoms generally parallel the rate of development and degree of hyponatremia [Devita and Michelis 1993].

Fluid Replacement

Palatability of any fluid replacement solution is important to ensure adequate rehydration. There is evidence that adding sweeteners to drinks leads to increased consumption. Glucose-electrolyte solutions have been shown to facilitate sodium and water absorption. Also, the glucose in these solutions provides energy for muscular activity in endurance events that require vigorous exercise [Rolls et al. 1990]. However, workers should be cautioned to avoid drinking large amounts of sugar laden beverages in hot climates as this will precipitate an osmotic diuresis that increases fluid loss through urination. Caffeinated beverages and alcohol intake will also increase urinary fluid loss and should be avoided. The temperature of the drink will also influence consumption of fluids. Ideally, fluids should be ingested at 50°F–60°F in small quantities (5–7 ounces) and frequent intervals (every 15–20 minutes).

Average Americans consume adequate, if not excessive, amounts of sodium in their usual diet such that for mild dehydration, only water replacement is needed. However, in moderate dehydration or when involved in events resulting in prolonged sweating, electrolyte (i.e., sodium) replacement is indicated. There are many oral electrolyte replacement formulas or sports drinks available on the market. Salt tablets are not recommended as they can irritate the stomach, leading to vomiting which can exacerbate fluid losses and do not address water replacement needs. Those with nausea and vomiting from heat stress may require intravenous saline administration to replace their water and sodium.

Ergonomics

Overexertion injuries and musculoskeletal disorders, such as low back pain, tendinitis, and carpal tunnel syndrome, are often associated with job tasks that include: (1) repetitive, stereotyped movement about the joints; (2) forceful manual exertions; (3) lifting; (4) awkward and/or static work postures; (5) direct pressure on nerves and soft tissues; (6) work in cold environments; or (7) exposure to whole-body or segmental vibration [Armstrong et al. 1986; Gerr et al. 1991; Rempel et al. 1992; NIOSH 1997]. The risk of injury appears to increase as the intensity and duration of exposures to these factors increases and the recovery time is reduced [Moore and Garg 1995]. Although personal factors (e.g., age, gender, weight, fitness) 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 [Armstrong et al. 1993].

In all cases, the preferred method for preventing and controlling work-related musculoskeletal disorders is to design jobs, work stations, 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 Tower Automotive were review of videotapes of job tasks to determine if there were any ergonomic risk factors such as awkward postures or highly repetitive movements.

Noise

Noise-induced loss of hearing is an irreversible, sensorineural condition that progresses with exposure. Although hearing ability declines with age (presbycusis) in all populations, exposure to noise produces hearing loss greater than that resulting from the natural aging process. This noise-induced loss is caused by damage to nerve cells of the inner ear (cochlea) and, unlike some conductive hearing disorders, cannot be treated medically [Ward et al. 2000]. While loss of hearing may result from a single exposure to a very brief impulse noise or explosion, such traumatic losses are rare. In most cases, noise-induced hearing loss is insidious. Typically, it begins to develop at 4000 or 6000 Hz (the hearing range is 20 Hz to 20000 Hz) and spreads to lower and higher frequencies. Often, material impairment has occurred before the condition is clearly recognized. Such impairment is usually severe enough to permanently affect a person's ability to hear and understand speech under everyday conditions. Although the primary frequencies of human speech range from 200 Hz to 2000 Hz, research has shown that the consonant sounds, which enable people to distinguish words such as "fish" from "fist," have still higher frequency components [Suter 1978].

The dBA is the preferred unit for measuring sound levels to assess worker noise exposures. The dBA scale is weighted to approximate the sensory response of the human ear to sound frequencies near the threshold of hearing. The decibel unit is dimensionless, and represents the logarithmic relationship of the measured sound pressure level to an arbitrary reference sound pressure (20 micropascals, the normal threshold of human hearing at a frequency of 1000 Hz). Decibel units are used because of the very large range of sound pressure levels which are audible to the human ear. Because the dBA scale is logarithmic, increases of 3 dBA, 10 dBA, and 20 dBA represent a doubling, tenfold increase, and 100-fold increase of sound energy, respectively. It should be noted that noise exposures expressed in decibels cannot be averaged by taking the simple arithmetic mean.

The OSHA standard for occupational exposure to noise [29 CFR 1910.95] specifies a maximum PEL of 90 dBA for a duration of 8 hours per day. The regulation, in calculating the PEL, uses a 5 dB time/intensity trading relationship, or exchange rate. This means that a person may be exposed to noise levels of 95 dBA for no more than 4 hours, to 100 dBA for 2 hours, etc. Conversely, up to 16 hours exposure to 85 dBA is allowed by this exchange rate. The duration and sound level intensities can be combined in order to calculate a worker's daily noise dose according to the formula:

$$\text{Dose} = 100 \times (C_1/T_1 + C_2/T_2 + \ldots + C_n/T_n),$$

where C_n indicates the total time of exposure at a specific noise level and T_n indicates the reference duration for that level as given in Table G-16a of the OSHA noise regulation. During any 24-hour period, a worker is allowed up to 100% of his daily noise dose. Doses greater than 100% are in excess of the OSHA PEL.

The OSHA regulation has an additional AL of 85 dBA; an employer shall administer a continuing, effective hearing conservation program when the 8-hour TWA value exceeds the AL. The program must include monitoring, employee notification, observation, audiometric testing, hearing protectors, training, and record keeping. All of these requirements are included in 29 CFR 1910.95, paragraphs (c) through (o). Finally, the OSHA noise standard states that when workers are exposed to noise levels in excess of the OSHA PEL of 90 dBA, feasible engineering or administrative controls shall be implemented to reduce the workers' exposure levels.

NIOSH, in its Criteria for a Recommended Standard [NIOSH 1998], and ACGIH [ACGIH 2007], propose exposure criteria of 85 dBA as a TWA for 8 hours, 5 dB less than the OSHA standard. The criteria also use a more conservative 3 dB time/intensity trading relationship in calculating exposure limits. Thus, a worker can be exposed to 85 dBA for 8 hours, but to no more than 88 dBA for 4 hours or 91 dBA for 2 hours. Twelve-hour exposures have to be 83 dBA or less according to the NIOSH REL.

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Acknowledgements and Availability of Report

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