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Work-Related Musculoskeletal Symptoms and Injuries Among Operating Engineers: A Review and Guidelines for Improvement

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Among construction workers, operating engineers encounter job factors considerably different from those of their counterparts in other construction trades. While many professionals in the construction trades are faced with risk factors for work-related musculoskeletal disorders (WMD) such as heavy lifting, carrying, power tool use, and forceful repeated motions, operating engineers are confronted with more subtle stressors. The sustained and awkward postures they are required to maintain, the controls they are required to operate, and the vibrating environments in which they work are major risk factors for WMDs among operating engineers. This article reviews the current literature and recommendations for improvement. Considering symptom and disability prevalence rates along with biomechanical and physiological considerations, four primary recommendations to reduce WMDs are indicated. Equipment designs should minimize the magnitude and frequency of vibration reaching the operator. Placement of equipment controls within the cab should minimize reach distance and trunk flexion and rotation. Cab designs should provide maximum operator visibility from an upright seated posture, decreasing postural loads associated with trunk and neck flexion. Operators should be encouraged and allowed to take regular breaks during the workday, minimizing the effects of a sustained sitting posture. These modifications in equipment and work practices should reduce the rates of musculoskeletal disorders associated with the operating engineer's profession and work environment. ZIMMERMANN, C.L.; COOK, T.M.; ROSECRANCE, J.C.: WORK-RELATED MUSCULOSKELETAL SYMPTOMS AND INJURIES AMONG OPERATING ENGINEERS: A REVIEW AND GUIDELINES FOR IMPROVEMENT. *APPL. OCCUP. ENVIRON. HYG.* 12(7):480-484; 1997. © 1997 AIH.

According to the Bureau of Labor Statistics,⁽¹⁾ the construction industry leads all other industrial divisions in the number of nonfatal injuries or illnesses. In 1994 the construction industry was second only to transportation/public utilities in the number of sprains and strains and led in cuts/lacerations and fractures. The number of injuries per 100,000 workers, by body part, was greatest among construction workers for head, eye, trunk, back, upper extremity, hand, finger, lower extremity, knee, foot, toe, and multiple body parts.

Among construction workers, operating engineers encounter job factors that are considerably different from those of their counterparts in other construction trades. While many professionals in the construction trades are faced with risk factors for

work-related musculoskeletal disorders (WMDs) such as heavy lifting, carrying, power tool use, and forceful repeated motions, operating engineers are confronted with more subtle stressors. The sustained and awkward postures they are required to maintain, the controls they are required to operate, and the vibrating environments in which they work are major risk factors for WMDs among operating engineers.

Overview

Work-Related Musculoskeletal Disorders Among Operating Engineers

Studies of operating engineers have ranged from injury prevalence descriptive studies to case-control investigations which have made comparisons between different groups of operating engineers or between operating engineers and age-matched sedentary control groups. Operating engineers operate numerous kinds of equipment for various purposes. This equipment may also be used to pull various implements. One of the difficulties in studying operating engineers has been the fact that many operators are trained on and operate many different pieces of equipment, with operation of four to six different pieces of equipment being very common.⁽²⁾ This fact makes it difficult to evaluate the relative risks associated with operating any specific type of equipment, although a limited number of studies have been undertaken to begin to address the relative risks associated with specific equipment types.

BULLDOZER OPERATORS. The most prevalent work-related symptoms reported among bulldozer operators include stiff shoulder (54.3%), general fatigue (44.1%), low back pain (LBP; 36.2%), weak stomach (34.6%), and irritability (33.9%).⁽³⁾ These values are apparently point prevalences for 127 operators who worked solely with bulldozing equipment; however, no time frame information was provided. Unfortunately, whether the bulldozers used by the subjects in the study were tracked or wheeled was not reported. This is a concern since the vibration levels for these two types of bulldozers differ significantly: 0.3 to 1.3 m/s² for tracked and 0.6 to 2.2 m/s² for wheeled.⁽⁴⁾

CRANE OPERATORS. Overhead crane operators, as part of a retrospective follow-up study, have been identified as being at higher risk for permanent work disability due to back disorders (in particular disorders of the intervertebral disc) when compared with a control group of male factory workers employed in the same departments.⁽⁵⁾ The job description given for the crane operators in this study included a minimum of 6 hours

daily exposure to whole-body vibration (WBV), a minimum of 6 hours daily sustained sitting posture (often associated with bending forward), very little physical stress, a changing climate (hot/cold), and high psychological stress. The control group job description included vibration exposure for one-third of the group 20 percent of the time, prolonged sitting and standing, bending forward and standing (20% of the day), heat stress, and little psychological stress. They reported incidence density ratios (IDRs) (case versus control) of 2 and 2.95 for disability due to intervertebral disc disorders and degeneration of the intervertebral disc, respectively. These ratios showed a pattern of increasing disability with increasing duration of WBV exposure among crane operators. When adjusting these ratios for potential confounding factors, the IDRs increased to 2.28 and 3.28, respectively. Over time these differences amounted to almost 24 percent disability pensioning among crane operators versus 8 percent for controls by age 55. Bongers *et al.*⁽⁶⁾ also investigated the prevalence of sickness absenteeism of 28 days or greater duration in the same population. This investigation identified no difference between cases and controls. However, the duration of absenteeism related to low back disorders among the crane operators was greater than that reported for the controls. Thus, with the same number of reported incidents, the crane operators, on average, missed a greater amount of work.

Burdorf and Zondervan⁽⁷⁾ examined 33 steel factory crane operators. Of their sample, 61 percent reported LBP and 27 percent reported LBP with sciatica in the previous 12 months. This compared with 27 and 10 percent reporting similar problems in their control group. It should be noted that among the crane operators experiencing LBP none could identify a specific incident that brought on their symptoms. The duration of LBP [less than 2 days (29%), lasting 3 to 7 days (33%), lasting 1 to 3 weeks (17%), and daily LBP (21%)] and history of recurrence [pain for 1 year or less (43%), pain for 2 to 5 years (36%), pain for 6 to 10 years (7%), and pain for 11 to 20 years (11%)] were similar among the operators and controls. Considering the differences in LBP among the cases and controls, an odds ratio (3.6) was determined for risk of LBP among crane operators versus controls. In another investigation of crane operators, Burdorf *et al.*⁽⁸⁾ identified a 12-month LBP prevalence of 50 percent among crane operators. They also identified an odds ratio of 3.29 for newly developed cases of LBP among crane operators versus office workers.

EARTH-MOVING EQUIPMENT OPERATORS. Dupuis and Zerlett⁽⁴⁾ performed a three-part investigation of operators of earth-moving equipment. The first part of the investigation was a cross-sectional study (interviews and medical examinations) of 352 operators of earth-moving machinery with at least 3 years of work experience. X rays of 251 machine operators from this group with over 10 years of experience were also reviewed. In an investigation of subjective perspectives, 149 operators were asked about the experience of discomfort immediately following an 8-hour workday. The results indicated that the primary problems during the previous 12 months for the earth-mover operators (352) in this study were LBP (68.7%), discomfort during the work shift (75%), discomfort after the shift (59%), and disorders of the spine (70%). The majority of the discomfort in the spine was attributed to the

lumbar region (68.7%). The predominant health impairment among the operators was lumbar syndrome (81%). In this study, "lumbar syndrome" followed the definition of Kr  mer:⁽⁹⁾ "symptoms which are caused directly or indirectly by degenerative lesions of the lumbar discs." Of the workers questioned immediately following the work shift ($n = 149$), the following were reported; backache (45%), discomfort (40%), paraesthesia in the arms and legs (21.5%), headache (19.5%), and tiredness (11%). The prevalence of backache was seen to increase with age from 20 to 29 years (35%) to 50 to 59 years (67%).

FORKLIFT OPERATORS. In an evaluation of work-related symptoms, Miyashita *et al.*⁽³⁾ reported that the most prevalent complaints among 44 forklift operators were stiff shoulder (56.8%), LBP (50.0%), general fatigue (45.5%), weak stomach (38.6%), and upper and lower extremity paraesthesias (22.7%).

Bendstrup and Biering-S  rensen⁽¹⁰⁾ evaluated 169 forklift truck operators and compared them with two control groups (salaried or skilled workers and unskilled laborers). Lifetime incidence of LBP varied across the three groups: forklift truck drivers (79%), skilled workers (63%), and unskilled workers (64%). Retrospective prevalences measured included the 12-month prevalence of LBP (65, 47, and 52% for the three respective groups) and missed work due to LBP (22% of forklift truck drivers and 7 and 9% of the respective controls). Point prevalences of LBP were reported as 21, 11, and 8 percent. Reports of low back trouble during a follow-up year were as follows: forklift truck drivers (51%), skilled workers (43%), and unskilled workers (47%). Absence due to LBP was reported by 17, 7, and 3 percent, respectively. Treatment for LBP was obtained by 16, 13, and 9 percent, respectively.

Boshuizen *et al.*⁽¹¹⁾ evaluated self-reported back pain among a group of 242 forklift truck and freight container tractor drivers. Differences noted between the drivers and the control group included: (1) increased smoking, (2) increased mental stress, (3) sitting more frequently, (4) sitting longer without interruption (58% report sitting for more than 2 hours without interruption), (5) looking backward frequently, and (6) WBV exposure at 0.8 to 1 m/s^2 a_{wv} . This study reported prevalences among the drivers of back pain (48%), LBP (41%), work-related transient back pain (20%), lumbago (19%), and tingling in legs (21%), which were all significantly greater than that reported in the control group. Their prevalences are lower than those reported by other investigations, and this may be attributed to differences in questionnaire wording. However, the significant differences in back pain still exist. Odds ratios were determined and found to be significant for back pain (2.3), LBP (2.2), back pain lasting several days or more (1.22), point prevalence of back pain (1.17), and 1-year prevalence of back pain (1.28). The authors also report a health-based selection among the drivers, with drivers experiencing back pain being more likely to select out of the profession.

In a cross-sectional analysis of three sedentary trades, Burdorf *et al.*⁽⁸⁾ identified an odds ratio of 2.51 for newly developed cases of LBP when comparing straddle-carrier drivers to office workers. The 12-month prevalence of LBP among drivers was 44 percent, compared with 34 percent for office workers and 50 percent for crane operators.

POWER SHOVEL OPERATORS. A study by Miyashita *et al.*⁽³⁾ identified the following work-related symptom prevalence among 184 power shovel operators: stiff shoulder (43.5%), LBP (38.0%), irritability (29.3%), weak stomach (27.2%), and general fatigue (26.6%). These findings are very similar to those reported for bulldozer operators and forklift operators. The forklift operators showed significant differences when compared with the control group, whereas the bulldozer and power shovel operators did not.

TRACTOR OPERATORS. In a pair of 1990 publications, Boshuizen *et al.*^(12,13) reported an increased tendency for earlier disability pensioning among tractor drivers when compared with controls from the same company. They also reported an elevated incidence of long-term absenteeism because of intervertebral disc disorders among the tractor drivers. The general sentiment of the authors was that a positive association existed between the years of exposure to WBV and the likelihood of disorders of the back and intervertebral disc. They also provide a summary of the prevalences of LBP found in previous studies on tractor drivers.⁽¹⁴⁻¹⁸⁾ Reports from other studies mentioned ranged from 24⁽¹⁹⁾ to 61 percent,⁽²⁰⁾ depending on the definition of prevalence and LBP in the study.

GENERAL. Milby and Spear,⁽²⁾ in a review of 3900 medical claims over a 20-month period made by members of IUOE Local No. 3 (Northern California) reported a bias among the group that indicated persons exposed to WBV were likely to self-select out of occupations when suffering from certain disease conditions such as ischemic heart disease, nonendocrine-related obesity, and displacement of intervertebral discs. Spear *et al.*,⁽²¹⁾ in a follow-up to the 1974 study of Milby and Spear,⁽²⁾ indicated that there was a greater tendency for self-selection out of the work environment for vibration-exposed workers than for controls. They also indicated that the overall prevalence of disease processes among cases and controls was not significantly different, but that for vibration-exposed workers there was tendency for earlier manifestation of the disease or injury processes. Spear *et al.*⁽²²⁾ have reported an interesting trend in the work patterns of operating engineers. In reviewing their 1974 and 1975 studies of heavy equipment operators, they noted a trend of injury and disability claims among the operators. As the work experience of the operators increased, their rate of reporting claims decreased. This pattern was not, however, linear. There was an increase in claims as the number of pension credits increased from 0 to 19.75, and then a decrease for workers with 20 or more pension credits. This trend has been associated with a self-selection process where persons unable to tolerate their work environment self-select out of that environment.⁽²³⁾ A similar trend was noted among construction machinery operators⁽²⁴⁾ for disorders including osteomyelitis, intervertebral disc displacement, and structural bone and joint deformities.

Most of the previous studies have focused on LBP and spinal disorders. Riihimäki *et al.*⁽²⁵⁾ and Viikari-Juntura *et al.*⁽²⁶⁾ have performed investigations on a group of earth-mover operators and longshoremen. These two groups served as the machine operating group in a cross-sectional and 3-year follow-up study of three types of work: operating machines, dynamic physical work, and sedentary work. Investigation of sciatic pain

incidence identified a 3-year cumulative incidence rate of 22 percent for equipment operators versus 14 percent for office workers and an adjusted rate ratio of 1.4 for the machine operators when compared with office workers.⁽²⁵⁾ Tola *et al.*⁽²⁷⁾ have also investigated the prevalence of neck and shoulder symptoms among these three types of work. The machine operators selected in their evaluation included earth-moving machine operators (excavators, bulldozers, loaders, etc.) and longshoremen (forklift truck). Due to the variety of equipment operated by their sample, they are included in this section. Results of their study identified an 81 percent lifetime prevalence of neck and shoulder symptoms among machine operators. The 12-month prevalence of neck and shoulder symptoms was only slightly lower, while the 7-day symptom prevalence was near 58 percent. In an evaluation of risk indicators it was noted that working in bent or twisted postures increased the occurrence of neck and shoulder symptoms, especially among the equipment operators. The relative risk of neck and shoulder symptoms for machine operators versus office workers was 2.4.

Risk Factors for Work-Related Musculoskeletal Disorders

A review of the biomechanical and physiological literature indicates that the high prevalence of WMDs among operating engineers might be attributed to a combination of prolonged and often awkward sitting and exposure to WBV. Exposures to extremes of temperature and humidity are most likely confounding factors.

PROLONGED (AWKWARD) POSTURES. The task of equipment operation is typically performed in a seated posture. Several classic investigations^(28,29) have shown an increase in intradiscal pressures for unsupported sitting compared with standing. Numerous investigators have implicated static sitting as a major cause of LBP.⁽³⁰⁻³²⁾ Additionally, the adoption of a kyphotic (forward bent) lumbar spine posture has been implicated in further enhancing the negative effects of prolonged sitting.^(30,33) Within unsupported sitting postures, the greatest intradiscal pressures are reported for postures of forward bending. These postures are also coincident with increases in erector spinae muscle activity.⁽³⁴⁾ Thus, the seated posture has a significant influence on intradiscal pressure and the muscular demands during static sitting. The risks associated with leaning forward in a driver's seat have been further demonstrated by a study of various lumbar supports. Increasing the thickness of the lumbar support up to 5 cm has been shown to result in decreased electromyographic (EMG) and intradiscal pressure.⁽²⁹⁾ The role of posture in LBP has also been investigated and objectified in several cross-sectional analyses of employees in sedentary and nonsedentary occupations.⁽³⁵⁻³⁹⁾

The effects due to awkward postures noted for the back are also present in the prevalence of problems in the neck and shoulder. In the neck, static awkward postures can result in increased intradiscal pressure and increased muscular demands. These muscular demands are determined by the net moment created by the head relative to the vertebral level of interest and the relative length of the muscle. Greater moments lead to a greater stabilizing force requirement, and shortened or elongated muscle lengths (relative to resting length) decrease the

muscle's ability to generate force and thereby increase the probability of fatigue.

In the case of the shoulder, static postures and repetitive motions are probably the key determining factors.^(40,41) Static elevated arm postures lead to increased fatigue in a manner similar to awkward head postures (increased mass moment arm and inefficient muscle lengths).

REPETITIVE MOVEMENTS. Repetition is an occupational risk factor that may contribute to the problems in the neck, shoulders, and low back. If the job requirements include repeated backward looking, this maneuver may generate tension on the intervertebral disc's annulus⁽⁴²⁾ and apply repetitive loading to the musculature.⁽⁴³⁾ This may lead to structural fatigue of the disc's lamina⁽⁴²⁾ or muscular fatigue. The repetitive nature of hand control manipulation may lead to fatigue and injury of the shoulder, forearm, and hand.⁽⁴⁰⁾ Any repetitive movements out of a neutral lumbar spine position (forward or side bending and rotation) will have effects on the disc and musculature similar to those noted for the neck.

WHOLE-BODY VIBRATION. The WBV epidemiology literature has identified that sitting in a driving or vibratory environment produces even greater risk of LBP or back injury when compared with static sitting.^(4,22,39,44-51) This greater risk has been attributed to two potential mechanisms: (1) materials fatigue of the vertebral endplate due to repeated loading and subsequent scarring resulting in decreased nuclear nutrition and disc failure; and (2) degenerative changes in the annulus due to excessive mechanical loading of the annular fibers.⁽⁵²⁾ Both of these phenomena may be occurring in workers exposed to WBV while in neutral and nonneutral seated postures.

The response of the musculature during WBV exposure is an important factor and has been classified into two separate categories: tonic and phasic activities (sometimes referred to as a vibration synchronous response). Regarding erector spinae activity during WBV exposure, there exist conflicting reports of increases in tonic EMG activity with⁽⁵³⁾ and without⁽⁵⁴⁾ accompanying increases in the phasic EMG component.

Considering the physiological evidence, the International Organization for Standardization (ISO) has addressed the issue of WBV exposure in their guideline ISO 2631-1.⁽⁵⁵⁾ This guideline establishes limits for WBV exposure based on its direction of application, magnitude, and frequency. The frequencies at which exposure duration is most limited are in the range of 4 to 8 Hz, with increasing duration of exposure being acceptable at higher and lower frequencies. Thus, within the operating engineer's working environment, the negative effects attributed to sitting are present along with the negative effects associated with WBV exposure.

The preceding has been an attempt to consolidate a body of literature which sorely lacks consistency in measurement and reporting. It should be noted that in many cases self-reported symptoms are the measurand of choice, and some of the disorders investigated may have significant cultural ties. It is hoped that this article will allow the reader to better understand the complexities of the operating engineer's work environment and how it affects operators. It is also hoped that this review will begin to consolidate some of the literature and bring into focus the lack of organization in research methods and reporting of WMDs among operating engineers. Attempts

by the authors to produce a consolidating table which would or could adequately represent the state of knowledge concerning operating engineers and WMD were unsuccessful due to the variety of measurands used and types of investigations reported in the literature.

Recommendations

Based on currently available information, four guidelines for reducing WMDs among operating engineers seem warranted:

1. Equipment should be designed to minimize the magnitude and frequency of vibration reaching the operator.
2. Equipment controls should be located within the cab such that reach distance and trunk flexion and rotation are minimized.
3. Cabs should be designed to provide the maximum operator visibility from an upright supported seated posture, thus decreasing the postural load associated with trunk and neck flexion.
4. Equipment operators should be encouraged to take regular breaks during the workday to minimize the effects of sustained postures.

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