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Exposure to Musculoskeletal Workplace Factors for Railroad Locomotive Shop Workers

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Abstract: The physical demands of the North American railroad locomotive shop worker positions have been described, historically, in subjective terms. These descriptions have been based on subject matter experts and railroad employees. Research has demonstrated that subjective accounting of the intensity, frequency, and duration of physical exposures of the work, to be notably less accurate than the actual physical exposures. Additionally, it is important to account for the whole shift of exposure to physical demands. Objectively based data collection and analysis of the locomotive shop worker positions has been conducted through multiple job studies at different railroad shop locations across the country, over several years. Results of this study provide reliable exposure data and suggest that there is generally not an increased relative risk for the development of a variety of musculoskeletal disorders.

Keywords: Railroad, Locomotive Shop, Musculoskeletal

1. Introduction

The railroad locomotive shop worker is a part of the Mechanical Department in a railroad company. The Mechanical Department is responsible for inspecting and maintaining the rolling stock (railroad cars) and locomotives. This paper will focus on the locomotive shop's maintenance and repair work, which is conducted by several trades of employees, including the machinist, electrician, pipefitter, and boilermaker. These trades perform FRA required periodic locomotive inspection and maintenance, required component replacements, overhauls, project upgrades, collision repairs, and even locomotive rebuilds. Locomotive shops contain all manner of cranes and lifting devices that are designed for lifting everything from various locomotive components to larger sections of locomotives. Locomotive shops are constructed with drop pits, raised rails for work done underneath a locomotive, and platforms that are at the level of the locomotive catwalks. Locomotives are brought into and out of the shop area, on the shop's rail system that is continuous with a rail yard facility. Numerous specialized tools and adaptors have been designed and crafted to support the work of the locomotive shop worker. There are also numerous typical and specially designed power and hand tools used in the locomotive shop. Depending on the locomotive work needed, the locomotive shop's contingent of trades workers would be organized and assigned their work, normally on a shift-by-shift basis. The locomotive shop generally operates 24/7 throughout the year, where workers bid on one of 3, 8-hour shifts, as their seniority and trade specialty permit. Throughout the shift, a locomotive shop worker may use various power tools and hand tools, operate equipment (i.e., crane, forklift), handle parts, and work with diagnostic instruments. While efforts are made to permit the locomotive shop worker to conduct their duties in preferred body postures, there may occur postures like squatting, kneeling, bending, or working overhead.

An initial description of physical job demands and exposures for locomotive shop workers was developed in the late 1970's (Lawshe, 1977). However, this description was based on consensus, subjective estimates of job exposures and job task demands, not on the objective quantification of job exposures. These Lawshe descriptions used to be factored into decision-making related to hiring, return-to-work, and the determination of work-relatedness of adverse health effects by human resources departments and occupational medicine professionals. In an October 3, 1993 advisory letter, the Railroad

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Personnel Association, which originally commissioned the Lawshe studies, withdrew the Lawshe job descriptions due to their lack of relevance to contemporary railroad operations. Around this same time, the railroad industry began to experience claims for non-acute adverse musculoskeletal conditions, which remains the case today. Acute as well as non-acute occupational musculoskeletal injury claims can be investigated using the science of ergonomics in a systematic, objective approach. Accordingly, the authors of this article began to develop objective, detailed accountings of the physical job demands experienced by the North American locomotive shop employee. There have been long-standing guidelines advanced by the National Institute of Occupational Safety and Health (NIOSH) to support decision-making efforts for the work-relatedness of adverse health effects attributed to occupational exposures (Glass, 2004; Kusnetz & Hutchison, 1979; Melhorn & Ackerman, 2008).

This article presents the results of objectively based analyses investigating exposures to occupational physical factors for railroad Mechanical Department locomotive shop workers. This data may be used in several capacities, including in evaluating the risk of work-relatedness for the development of musculoskeletal disorders.

2. Methods

Locomotive shop workers performing their regular jobs were observed, measured, and continuously video recorded. If the job involved a cyclical process, a reasonable number of cycles were video recorded and production records were incorporated to generate a typical shift workload. For jobs that did not involve a cyclical process, the recorded video of the worker was continuously captured over the duration of their work shift. This collection of data for the locomotive shop worker's job was obtained intermittently, over several years. The distribution of exposure to workplace factors over the duration of the shift was determined using randomized work sampling analysis, which provided ±2.5% precision at a 95% level of confidence (Chaffin, et al., 2006; Li & Buckle, 1999; Niebel, 1982; Pape, 1992). Each of the locomotive shop worker jobs was analyzed separately, normalized to the percent duration of the shift, and subsequently averaged. It typically takes approximately 40 hours of time for an analyst to complete a single randomized work sampling job study. The workplace factors analyzed historically have varied from one job study to another, and as such, the number of jobs included in these averages vary, but mostly to a minor amount. The number of locomotive shop worker job studies included in the randomized work sampling analysis was 20 for hand activity (n=20), 16 for shoulder posture (n=16), 19 for whole body posture (n=19), 17 for torso flexion posture (n=17), and 16 for each of standing and walking surfaces (n=16). Since the number of job studies used in the work sampling averages change among the factors studied, it should be noted that the "beginning/end of shift" and the "break/no work activity" categories aren't the same, when the shift n-values are different.

The locomotive shop worker engages in the use of tools, or the performance of distinct actions when performing their work. Several of these select actions, that are more typical, were tracked for each job study from reviewing the continuous video record. Each select action (i.e., use of a tool, handling of a part or component) performed by the locomotive shop worker over the duration of the shift was counted and then the totals for each job study were averaged across shifts (n=16). Because of the diversity of the work conducted in a locomotive shop facility, not all workers use the same tools, or perform the same select actions. As such, certain select actions will be much more common across job assignments in comparison to others. The frequency distribution of lifting demands, throughout the shift was analyzed. Lifts were qualified as "lighter" and "heavier" based on a criterion of 35-lbs (Chaffin et al., 1988). An exemplar lifting distribution for a single shift of a locomotive shop worker is provided in this article.

The distal upper extremity (DUE) activities for the locomotive shop worker were analyzed using the Strain Index (SI) (Moore & Garg, 1994; Moore & Garg, 1995). The distal upper extremity use was categorized for the degree of effort based on the multiple different workplace actions. The various intensities of exposure were multiplied by the average duration each exposure was performed to provide an overall weighted average (Bao et al., 2009). The efforts per minute, hand/wrist posture, speed of work, and duration of task per day for the SI calculation were observed, measured, and analyzed from use of the video recordings and work sampling analysis. Research suggests that a threshold of increased risk is associated with SI scores that are greater than 6.1, and for more intermittent exposures an elevated threshold may be warranted, depending on the SI application (Garg et al., 2012; Meyers et al., 2014; Moore & Garg, 2006).

A timeline provides an objective accounting of the modes of work performance over the duration of the shift and offers context to the analysis of workplace factors. An exemplar timeline of a single shift of a locomotive shop worker is provided in this article. The timeline was developed from the continuous video record, along with notes from the job study data collection. It is not advised to average timelines because each work shift may contain some degree of uniqueness, particularly when the job involves less cyclical exposure.

The results of the exposure analyses for the locomotive shop worker are discussed as useful in the NIOSH approach for the determination of work-relatedness, particularly as it relates to the NIOSH step, termed *Evidence of Exposure* (Glass, 2004; Kusnetz & Hutchison, 1979; Melhorn & Ackerman, 2008).

3. Results

The average distribution of exposure to workplace factors, as determined by randomized work sampling, is presented in Tables 1-6. The distribution across categories for a particular breakdown of exposure to workplace factors, along with "beginning/end of shift" and "break/no work activity" sums to 100%, which represents the time that the locomotive shop worker is on duty. Table 1 presents the hand activity average (n=20) workplace factors. "General factor" is made up of "beginning/end of shift", "break/no work activity" and "hand idle", which combine to make up 69.7% (left hand) and 68.0% (right hand) of the duration of the shift. The "hand active factor" refers to diverse hand activity that usually occurred intermittently with negligible physical demand and amounted to 8.6% (left hand) and 7.4% (right hand) of the work shift. The average exposure to "performing locomotive shop work" is of ergonomics interest and was measured at 21.7% (left hand) and 24.6% (right hand).

Table 1. Average (n=20) Percent of Shift for Exposures to Workplace Factors for Hand Activity for the Locomotive Shop Worker.

Factor	Description	Percent of Shift	
		Left Hand	Right Hand
General Factor	beginning/end of shift	26.2%	26.2%
	break/no work activity	23.2%	23.2%
	hand idle	20.3%	18.6%
	General Factor: Sub-Total	*69.7%*	*68.0%*
Hand Active Factor	personal gear/hygiene	0.6%	0.7%
	PPE/safety equipment	1.4%	1.2%
	opening/closing doors	0.3%	0.3%
	handling trash	0.1%	0.2%
	using aerosol can	0.1%	0.1%
	using computer	0.6%	0.8%
	using flashlight	0.5%	0.7%
	bracing	1.4%	0.8%
	support	2.2%	1.3%
	paperwork/writing	1.4%	1.3%
	Hand Active Factor: Sub-Total	*8.6%*	*7.4%*
Performing Locomotive Shop Work	using hand tools	2.1%	2.9%
	using power tools	2.4%	3.0%
	handling parts & equipment	14.8%	15.0%
	operating equipment	2.3%	3.6%
	climbing	0.1%	0.1%
	Performing Locomotive Shop Work: Sub-Total	*21.7%*	*24.6%*
	Total for Shift	*100.0%*	*100.0%*

Table 2 presents the shoulder posture average (n=16) workplace factors. "Beginning/end of shift", "break/no work activity", and "neutral" make up the "general factor" and combine to make up 92.3% (left shoulder) and 92.9% (right shoulder) of the duration of the shift. Shoulder postures >60° of flexion and/or abduction, whether the arm is supported or not, as well as loaded or unloaded were considered beyond a neutral shoulder posture (Melchior, et al., 2006). Of ergonomics interest are shoulder postures >60° "unsupported/loaded" (i.e., supporting/using a tool overhead), which resulted in 2.4% (left shoulder) and 2.7% (right shoulder) of the duration of the average shift.

Table 3 presents the whole-body posture average (n=19) workplace factors for the locomotive shop worker. The "general factor" resulted in 50.4% of the duration of the shift. The locomotive shop worker spends 31.4% of the shift on average standing and lesser amounts of time sitting or walking. Only a very minor percent of the shift is spent climbing, kneeling, squatting, and lying, at a combined 3.4% of the work shift.

Table 4 presents the torso flexion posture average (n=17) workplace factors. The "general factor" which includes "neutral" torso posture averaged 90.9% of the shift. Torso flexion beyond neutral was defined as >20° and categorized as supported or unsupported. Of ergonomics interest is torso flexion bend >20° unsupported, which resulted in 4.5% of the work shift.

Tables 5 and 6 present the average (n=16) standing and walking surfaces workplace factors. The "general factor" makes up 54.6% of the duration of the work shift. Most of the other exposure is on a "asphalt-concrete" surface for standing at 19.1% and walking at 7.4% of the work shift.

Table 2. Average (n=16) Percent of Shift for Exposures to Workplace Factors for Shoulder Posture for the Locomotive Shop Worker.

Factor	Description	Percent of Shift	
		Left	Right
General Factor	beginning/end of shift	27.4%	27.4%
	break/no work activity	21.6%	21.6%
	neutral	43.3%	43.9%
	General Activity: Sub-Total	*92.3%*	*92.9%*
Shoulder Posture	>60° supported/loaded	2.8%	1.9%
	>60° supported/unloaded	1.7%	1.2%
	>60° unsupported/loaded	2.4%	2.7%
	>60° unsupported/unloaded	0.8%	1.3%
	Shoulder Posture: Sub-Total	*7.7%*	*7.1%*
	Total for Shift	*100.0%*	*100.0%*

Table 3. Average (n=19) Percent of Shift for Exposures to Workplace Factors for Whole Body Posture (WBP) for the Locomotive Shop Worker

Factor	Description	Percent of Shift
General Factor	beginning/end of shift	26.7%
	break/no work activity	23.7%
	General Factor: Sub-Total	*50.4%*
WBP	sitting	6.1%
	standing	31.4%
	walking	8.7%
	climbing	0.1%
	kneeling	1.8%
	squatting	1.0%
	lying	0.5%
	WBP: Sub-Total	*49.6%*
	Total for Shift	*100.0%*

Table 4. Average (n=17) Percent of Shift for Exposures to Workplace Factors for Torso Flexion Posture (TFP) for the Locomotive Shop Worker

Factor	Description	Percent of Shift
General Factor	beginning/end of shift	27.5%
	break/no work activity	23.7%
	neutral	39.7%
	General Factor: Sub-Total	*90.9%*
TFP	bend >20° supported	4.6%
	bend >20° unsupported	4.5%
	TFP: Sub-Total	*9.1%*
	Total for Shift	*100.0%*

Table 5. Average (n=16) Percent of Shift for Exposures to Workplace Factors for Standing Surfaces for the Locomotive Shop Worker

Factor	Description	Percent of Shift
	beginning/end of shift	29.6%

Factor	Description	Percent of Shift
General Factor	break/no work activity	25.0%
	General Factor: Sub-Total	*54.6%*
Standing Surfaces	not standing	17.4%
	dirt-gravel	1.9%
	asphalt-concrete	19.1%
	ladder	1.7%
	locomotive	5.3%
	Standing Surfaces: Sub-Total	*45.4%*
	Total for Shift	*100.0%*

Table 6. Average (n=16) Percent of Shift for Exposures to Workplace Factors for Walking Surfaces for the Locomotive Shop Worker

Factor	Description	Percent of Shift
General Factor	beginning/end of shift	29.6%
	break/no work activity	25.0%
	General Factor: Sub-Total	*54.6%*
Walking Surfaces	not walking	36.1%
	dirt-gravel	0.9%
	asphalt-concrete	7.4%
	ladder	0.1%
	locomotive	0.9%
	Walking Surfaces: Sub-Total	*45.4%*
	Total for Shift	*100.0%*

Table 7 presents the average (n=16) frequency that the locomotive shop worker performed various select specific workplace factors over the duration of the shift. A specific factor frequency less than 1.0 means that it was not performed during each shift that was analyzed. The most occurring specific factor was the use of an impact drill at 7.1 times per shift. Many specific factors were performed less than 1.0 times per shift.

Table 7. Average (n=16) Frequency of Select Specific Workplace Factors for the Locomotive Shop Worker Over the Duration of the Work Shift

Workplace Factor Description and Corresponding Number of Repeated Occurrences					
using impact drill	7.1	using welder	1.1	using water hose	0.3
using hammer	6.2	using large wrench	1.0	setting hand brake	0.2
using socket wrench	4.7	using pipe wrench	0.9	using slag remover	0.2
getting off equipment	4.3	using lining bar	0.9	using pump sprayer	0.2
getting on loco	3.7	using huck gun/ crab nut remover	0.9	using hydraulic jack	0.1
using brake bar/small lining bar	2.9	using grinder	0.8	using crescent wrench	0.1
operate controls	2.8	locking/unlocking railroad locks	0.7	using cutting torch	0.1
using combination wrench	2.6	using pliers	0.6	using utility knife	0.1
getting on equipment	2.5	operating valve	0.6	opening coupler	0.1
getting off loco	2.1	using manual jack	0.5	using channel locks	0.1
using screwdriver	1.3	pulling bleed rod	0.4	moving fuel hose	0.1
using overhead crane	1.3	using wheel chock	0.3	operating fuel trigger	0.1
replacing brake shoe	1.2	releasing handbrake	0.3	inserting fuel nozzle	0.1
setting up/ removing blue flag	1.1	connect hose	0.3	removing fuel nozzle	0.1

Figure 1 shows an exemplar lifting distribution workplace factor over a work shift for the locomotive shop work, for “lighter” lifts (less than 35-lbs) and “heavier” lifts (more than 35-lbs). In addition, lifting was categorized as one-handed or two-handed, to make up 4 different lifting categories. Figure 1 shows that lifting factors were of almost all “lighter”, one-handed lifts. The average of 6.5 lifts/hour (maximum 14 lifts/hour) for the exemplar locomotive shop worker shift compares, as an example, to another study that resulted in an average lifting frequency of 35.9 lifts/hour over the duration of the shift, which was a workplace factor that did not involve any reported back troubles (Pan et al. 1999). For the locomotive shop worker the exemplar lifting factor was generally performed on “lighter” parts, equipment and tools.

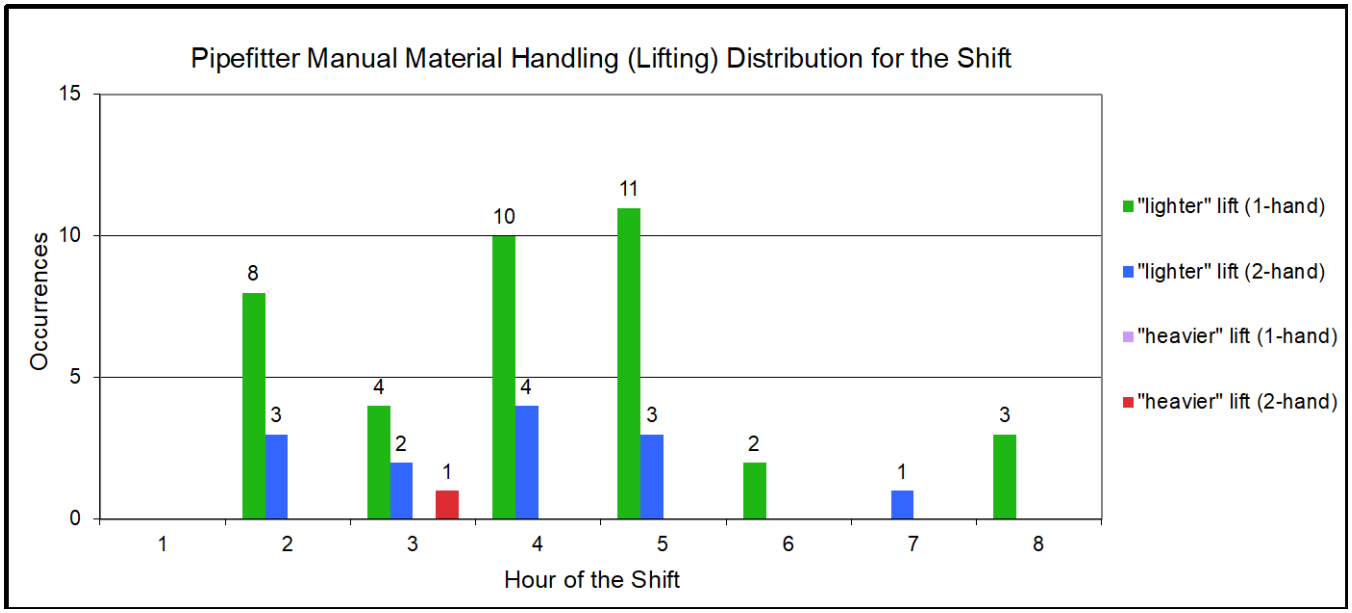

Figure 1. Exemplar Lifting Distribution Workplace Factor for the Locomotive Shop Worker Over the Duration of the Shift

The average (n=5) results of the SI analysis for the locomotive shop worker DUE factors were all below 6.1, with the greatest single SI score amounting to 3.6. The jobs that were included in this analysis result included 3 different trades and included both cyclical and non-cyclical locomotive shop work. An SI score below 6.1 is a generally agreed upon range which is not associated with an increased risk of distal upper extremity morbidity (Garg et al., 2012; Meyers et al., 2014; Moore& Garg, 2006).

Figure 2 presents an exemplar timeline for one of the locomotive shop worker job studies, that was included in this article. This timeline is from the same locomotive shop worker job study as the lifting distribution in Figure 1. This timeline is an accounting of the main work activities and when and for how long they took place over the duration of the work shift.

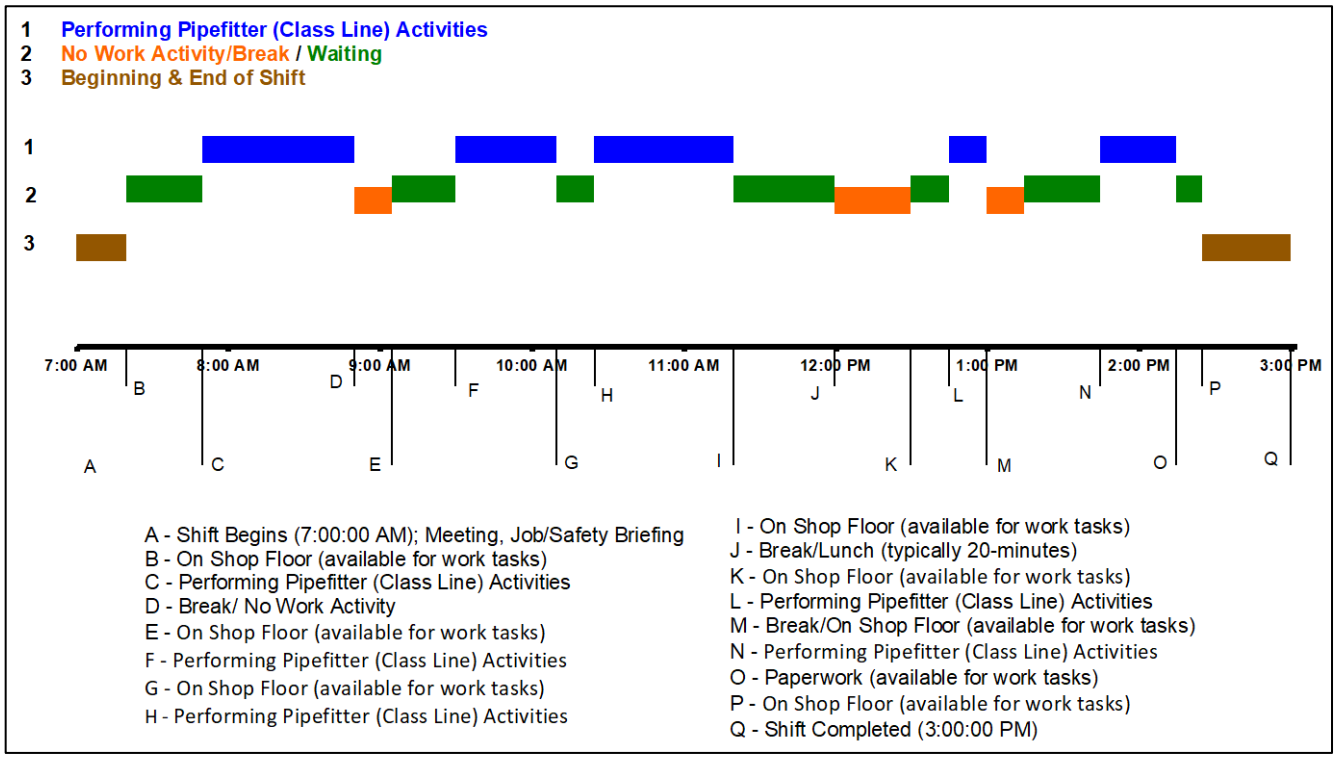

Figure 2. Exemplar Timeline Workplace Factor of a Locomotive Shop Worker Over the Duration of the Shift.

4 Discussion

The aim of this study was to provide objectively determined evidence for typical exposures to occupational physical factors for the locomotive shop worker job. This article provides perhaps the only objective analysis of the locomotive shop worker in the North American railroad industry.

The objectively measured exposures to workplace factors of ergonomics interest for the locomotive shop worker job can reasonably be characterized as occasional (US Department of Labor, 1991). The jobs included in this article consist of workplace factors that have not appeared in the scientific literature to be associated with an increased risk of musculoskeletal disorders generally. The results of this analysis can inform the *Evidence of Exposure* step in the paradigm for determining work-relatedness advanced by NIOSH (Kusnetz & Hutchison, 1979; Melhorn & Ackerman, 2008). In general, the locomotive shop worker job is not comparable to work that has been suggested by some researchers to be associated with musculoskeletal disorders (e.g., NIOSH, 1997). It is suggested that the locomotive shop worker occupational exposures provided here may be compared to the compendium of epidemiological literature for a more detailed risk evaluation.

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