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Physical ergonomic hazards in highway tunnel construction: Overview from the Construction Occupational Health Program

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ABSTRACT

This report provides an overview of physical ergonomic exposures in highway construction work across trades and major operations. For each operation, the observational method "PATH" (Posture, Activity, Tools and Handling) was used to estimate the percentage of time that workers spent in specific tasks and with exposure to awkward postures and load handling. The observations were carried out on 73 different days, typically for about 4 h per day, covering 120 construction workers in 5 different trades: laborers, carpenters, ironworkers, plasterers, and tilers. Non-neutral trunk postures (forward or sideways flexion or twisting) were frequently observed, representing over 40% of observations for all trades except laborers (28%). Kneeling and squatting were common in all operations, especially tiling and underground utility relocation work. Handling loads was frequent, especially for plasterers and tilers, with a range of load weights but most often under 15 pounds. The results of this study provide quantitative evidence that workers in highway tunnel construction operations are exposed to ergonomic factors known to present significant health hazards. Numerous opportunities exist for the development and implementation of ergonomic interventions to protect the health and safety of construction workers.

1. Introduction

Construction workers are exposed to a variety of ergonomic hazards, including awkward postures, heavy lifting, forceful exertions, vibrations, and repetitive motions (Schneider and Susi, 1994; Hartmann and Fleischer, 2005). They also experience an elevated risk of musculoskeletal disorders (Latza et al., 2000; O'Reilly et al., 2000; Sandmark et al., 2000; Schneider, 2001; Goldsheyder et al., 2002; Holmstrom and Engholm, 2003; Forde et al., 2005).

Much of the work performed in construction is non-routinized (Buchholz et al., 1996). This is due both to the dynamic nature of construction work itself and the changing external environment, which may impact the content and frequency distribution of job tasks across individuals and over time (Paquet et al., 2005). The dynamic nature of construction work also makes it difficult to measure ergonomic exposures systematically. A few investigators have used observational methods to determine the distribution of ergonomic exposures in specific construction trades or tasks (Wickstrom et al., 1985; Kivi and Mattila, 1991; Bhattacharya et al., 1997; Jensen and Eenberg, 2000). However, there have been few or no large-scale comparisons of exposure to physical ergonomic hazards among different trades or stages of the construction process. The objective of this report is to provide an overview of ergonomic exposures in highway construction work and to describe the frequency of known health hazards by the major trades and operations involved.

2. Methods

2.1. Study site and population

Data were compiled from 9 field studies that were carried out by ergonomists from the Construction Occupational Health Program (COHP) at the University of Massachusetts Lowell during the last decade (Buchholz et al., 1996; Kittusamy and Buchholz, 2001; Paquet et al., 2001; Buchholz et al., 2003; Paquet et al., 2005; Tak et al., 2009). All the studies took place at a very large highway

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construction site in Boston, Massachusetts. The operations were characterized according to a taxonomy that was created based on the Massachusetts Highway Department specifications (Moir et al., 2003). All observed workers were unionized, so the scope of work by each trade followed Massachusetts union jurisdictions. This study has been approved by the Institutional Review Board of the University of Massachusetts Lowell. All construction workers gave their informed consent prior to their inclusion in the study.

2.2. Data Collection

PATH (Posture, Activities, Tools, Handling) incorporates a modified work-sampling approach into observational job analysis. It provides unbiased estimates of the frequency of ergonomic exposures such as tasks, postures and load in the hands, linked to the tasks in which they are performed through concurrent recording of both, over multi-hour observation periods (Buchholz et al., 1996). Based on the Ovako Working Posture Analysis System (OWAS) (Karhu et al., 1977), the posture codes in PATH are defined as ranges of angles; for example, mild trunk flexion is defined as 20–45 of forward bending.

Codes for tasks, activities, and other exposures were developed *de novo*; many were customized to the specific trades following informal observations and discussions with workers and supervisors. Observers were rigorously trained and inter-observer agreement was confirmed before field data were collected.

In each study, we observed a single team of workers performing one operation on multiple days. A series of PATH observations were made at fixed intervals, either 45 or 60 s apart, typically for about 4 h per day. The observations cycled through all workers in the team, so multiple observations were made for each worker present on site each day.

2.3. Description of operations

A total of 9 separate operations were observed. To build concrete structures, ironworkers engaged in *Concrete Reinforcing* are responsible for placing and connecting steel rods (rebar) that reinforce concrete structures on construction sites. Carpenters then build forms around the steel rods (*Concrete Form Building*); the form-building operations are building, erecting and stripping forms. Construction laborers pour concrete into the forms (*Concrete Pouring*). Concrete is poured from a concrete pump truck through a hose. Some laborers use short handled shovels, lutes, or rakes to spread the concrete. Other laborers use large and small trowels to smooth out the concrete. Laborers also perform a variety of support tasks, such as erecting scaffolding, housekeeping, stripping forms, and manually excavating and fortifying shafts and tunnels.

Pipejacking is a common method to install underground piping, sewer lines, and electrical ducts 30 feet below the surface. It is an alternative to the traditional 'excavate, lay, and fill' pipe installation method, used especially when it is very important to minimize disruptions to surrounding activities or structures. Instead of digging deep trenches, two pits—a jacking pit and a receiving pit—are built initially. *Jacking Pit Construction* results in a pit that houses the equipment used to jack pipes through the soil. The pit is usually 30 feet × 30 feet × 30 feet with lagging installed around the sides to prevent the soil from caving in on the tunnelers while they work. After the jacking pit is completed, the pipes are then "jacked" through the soil to the receiving pit. Laborers assist the Tunnelers during both Jacking Pit Construction and Pipe-jacking.

The purpose of *Slurry Wall Construction* is to provide a barrier between a trench and the adjacent earth, to prevent earth from spilling into the trench (caving) and water intrusion. This requires below-grade excavation, through stabilizing slurry, to support the excavation walls. Due to the dangers of trenching and excavating, the use of slurry walls has increased greatly since it was first introduced in 1980's. Laborers perform manual excavation and housekeeping, often by breaking up large clumps of concrete that were not broken down by mixing, or rinsing any clay or slurry back into the trench to avoid slippage on the working surface.

Plastering, *Tiling*, and *Grouting* operations take place in the stage of tunnel wall finishing. During *Plastering*, plasterers apply finish coats of plaster to sections of the tunnel walls. After the first coat of concrete is applied, the "brown coat" is applied the next day on top of the first coat. Tilers then install and grout the tiles on the plastered section. During the *Wall Tiling* operation, tile finishers mix mortar, prepare the tile for setting and prepare the base of the wall for tiling, while tile mechanics are responsible for tile setting and supervising of the operation. In *Grouting*, tile finishers prepare the joints between the tiles, prepare the grout, grout and clean the tiles.

2.4. Data analysis

The proportion of observations for each task was estimated by operation. Exposure measures were computed as the percentage of the total work time accounted for by each exposure, i.e., proportion of time spent in trunk flexion, kneeling and squatting, etc. Descriptive data for trunk, leg and arm postures, and loads handled, were tabulated to provide operation- and trade-specific estimates of the proportion of time that workers were exposed to each ergonomic factor. Observations with missing information on trunk, leg, or arm postures were excluded from the analysis. Chi-square tests were performed to determine whether exposures varied among operations or trades.

3. Results

A total of 15,141 PATH observations were made on 73 days. These observations covered 120 construction workers in 5 different trades performing 9 operations (Table 1). Most operations had more than 5 days of observations except *Slurry Wall* (3 days), whereas four operations, *ConcreteForm Building*, *Concrete Reinforcing*, *Jacking Pit* and *Tiling*, had more than 12 days of observation.

Each operation consisted of at least four or more tasks; usually one or two primary tasks accounted for more than 20% of the total work time (Table 2). Of the 46 tasks observed, most were specific to

Table 1
Highway construction operations and workers observed on Central Artery/Third Harbor Tunnel project, Boston, MA, USA, 1995–2005.

Operation	No of days observed	Trade	No of workers observed	Tasks observed	No of observations
Concrete Form Building	14	Carpenters	15	8	1663
		Laborer	2		
Pipe Jacking	5	Tunneler[a]	3	4	1317
		Laborer	1		
Concrete Pouring	6	Laborer	7	5	743
Concrete Reinforcement	13	Ironworker	17	6	2027
Grouting	7	Tiler	18	5	1564
Jacking Pit	12	Tunneler[a]	1	5	3094
		Laborer	11		
Plastering	8	Plasterer	11	4	1642
Slurry Wall	3	Laborer	13	4	931
Tiling	14	Tiler	21	5	2160
Total	73		120	46	15,141

[a] Tunneler is a subspecialty of laborer, included within Laborers in subsequent tables and figures because of the small number of workers.