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PATH: A work sampling-based approach to ergonomic job analysis for construction and other non-repetitive work

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A high prevalence and incidence of work-related musculoskeletal disorders have been reported in construction work. Unlike industrial production-line activity, construction work, as well as work in many other occupations (e.g. agriculture, mining), is non-repetitive in nature; job tasks are non-cyclic, or consist of long or irregular cycles. PATH (Posture, Activity, Tools and Handling), a work sampling-based approach, was developed to characterize the ergonomic hazards of construction and other non-repetitive work. The posture codes in the PATH method are based on the Ovako Work Posture Analysing System (OWAS), with other codes included for describing worker activity, tool use, loads handled and grasp type. For heavy highway construction, observations are stratified by construction stage and operation, using a taxonomy developed specifically for this purpose. Observers can code the physical characteristics of the job reliably after about 30 h of training. A pilot study of six construction laborers during four road construction operations suggests that laborers spend large proportions of time in non-neutral trunk postures and spend approximately 20% of their time performing manual material handling tasks. These results demonstrate how the PATH method can be used to identify specific construction operations and tasks that are ergonomically hazardous. Copyright © 1996 Elsevier Science Ltd.

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Construction by its very nature is ergonomically hazardous, commonly requiring numerous awkward postures, heavy lifting and other forceful exertions (Schneider and Susi, 1994). When compared to other groups, construction workers show elevated risks of developing work-related musculoskeletal disorders (WMD) of the back, and the upper and lower extremities. In an epidemiological study of semi-skilled construction workers, Damlund *et al* (1982) found that 65% of the construction workers claimed a one-year prevalence of low-back pain vs 53% of a reference group of warehouse workers.

In a large cross-sectional study, Holstrom *et al* (1993) requested construction workers to complete an extensive questionnaire about their individual characteristics, and their experience with musculoskeletal symptoms and ergonomic exposures. The authors found that 92% of the workers had experienced musculoskeletal symptoms (localized pain ache or discomfort) during the previous year. The most prevalent symptoms were located in the back (72%), knees (52%), neck (37%) and right shoulder (37%). Frequent manual handling of machine equipment, and stooping and kneeling postures were associated with low-back pain, while frequent manual material handling tasks, and work with hands above shoulder height were associated with neck and shoulder pain. One important limitation of the study, however, was a potential bias in the self reports of exposure to ergonomics stressors (e.g. Burdorf and Laan, 1991; Wiktorin *et al*, 1993). Such limitations in exposure quantification are avoided with direct observational techniques.

In an assessment of the health and safety risks, and exposures associated with the work of manual construction laborers, Burkhart *et al* (1993) examined databases from the National Library of Medicine and the National Institute for Occupational Safety and Health in the United States, and the Health and Safety Executive in the United Kingdom. The authors found that although the job tasks of laborers were not well characterized, manual laborers appeared to have an increased risk of WMD, particularly of the back and wrists. However, the authors noted that only descriptive information about injury rates was available, and no scientific study linking exposures and health consequences of manual laborers existed. Study designs having improved quantification of exposures in construction work (particularly manual labor) are needed to determine the specific factors associated with WMD in construction.

Though construction workers show a high prevalence of WMD and are often required to assume non-neutral postures, perform strenuous manual material handling tasks, and operate hand and power tools that might increase the risk of developing musculoskeletal disorders, the ergonomic hazards of construction work have only been characterized crudely. The objective of this effort then was to develop a method for detailed characterization of the ergonomic risk factors present in the various construction jobs.

A number of methods for quantifying ergonomic risk factors have been previously developed. These methods include various observational techniques, as well as direct measurements using bioinstrumentation such as electromyography or electrogoniometry. Bioinstrumentation has been rarely used as a major tool for the collection of ergonomic hazards in construction for several reasons, including difficulties associated with worker mobility, obtrusiveness and cost. As technology advances, it is expected that the use of bioinstrumentation will increase, and in fact, recently a pair of overalls that use portable inclinometers and data loggers for collecting trunk posture data have been developed by Warren *et al* (1994) for use in the construction industry.

The most common observational techniques used to characterize ergonomic exposures are based on either time study or work sampling. Both of these techniques require a trained observer to characterize the ergonomic stressors. Time study-based methods (e.g. Armstrong *et al*, 1982; Keyserling, 1986) are usually used to create a continuous or semi-continuous description of posture and occasionally force level. Therefore, changes in the exposure level, as well as the proportion of time a worker is at a given level, may be estimated. Because time study-based methods tend to be very time intensive, they are better suited to work with fairly short and easily definable work cycles. A different approach, work sampling, involves observation of worker(s) at either random or fixed, usually infrequent time intervals and is more appropriate for non-repetitive work. Observations during work sampling provide estimates of the proportion of time that workers in a particular job devote to different tasks, spend in various postures and/or handle specified loads, although the sequence of events is lost.

Initial observations of the heavy highway construction industry suggested that, in general, the work was low on the continuum of repetitiveness. Much of the work is cyclical, although the cycles tend to be of relatively long duration and each cycle may be variable in its content (the number or sequence of steps that are performed by an individual worker may vary). When work is non-cyclical or the work cycles are long and irregular, a large portion of the work day needs to be recorded and analyzed in order to quantify accurately the proportion of time a worker may be exposed to a specified factor. An analysis strategy based on work sampling, in which exposure is recorded in the field in real time, therefore was selected for this endeavor.

One of the most commonly employed and simple work sampling-based methods is the Ovako Work Posture Analysing System [OWAS] (Karhu *et al*, 1977; 1981). OWAS categorizes posture using codes for the back, arms and legs, and another code to categorize load/effort. A computerized version of OWAS (COWAS) was developed by Kivi and Mattila (1991) which was used by Mattila *et al* (1993) to estimate the proportion of time that building construction workers spent in various back, arm and leg postures while performing hammering tasks.

A methodology for complete characterization of the ergonomic exposures in construction work has been developed. The methodology, which has been labeled PATH (Posture, Activity, Tools and Handling) and is presented below, incorporates the strengths of OWAS into a more comprehensive instrument. The OWAS method provided a basis for recording worker posture, but lacked a systematic link between posture and worker activity, which PATH includes.

PATH methodology

PATH, a work sampling-based approach, was developed specifically to characterize the ergonomic hazards of heavy highway construction work, and this presentation details that application. More recently, PATH has been generalized to building construction and to work in agricultural settings and should be easily adapted to other non-repetitive work. The analysis system has been piloted and revised over approximately two years to its present form. *Figure 1* shows the steps involved in applying the current methodology.

As a framework for the PATH methodology, a taxonomy was developed to describe the process of heavy highway construction. The taxonomy is organized hierarchically, with construction projects broken into a series of stages, and each stage is composed of one or several operations. *Table 1* lists the stages in the highway construction process, along with representative operations for each. On a large construction project, different stages can be underway simultaneously along the length of the site. Each operation is comprised of tasks that are performed by a specific trade, which is usually defined jurisdictionally. For example, pipe-laying is an operation in the drainage stage that is often performed by a crew that consists of an operating engineer, whose task is to operate an excavator, and a number of laborers, who assist by performing manual tasks such as shoveling and sealing.

A key underlying assumption of the PATH method is that ergonomic exposures are a function of the task performed, so that both the distribution of exposures within a task and the relative frequency at which a task is performed are needed in order to determine an exposure profile for an individual. For PATH, a task is defined as the largest group of activities that are normally performed together by a single worker in order to accomplish a common goal. Since the taxonomy allows the observations to be stratified by construction stage and operation, as well as by the trades involved in each operation, it provides the means for achieving a task-based analysis. A comparable taxonomy could be developed for other industries in order to facilitate a similar task-based analysis.

The first step in applying the PATH methodology is

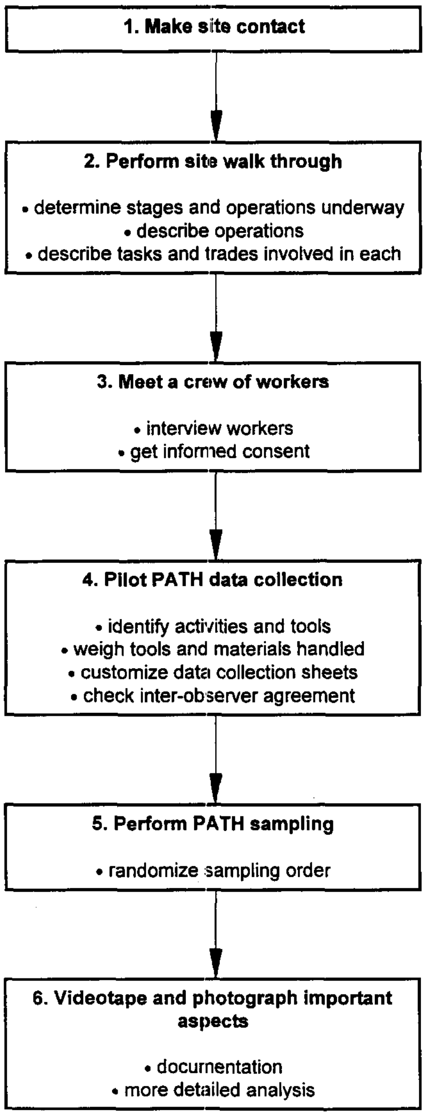

Figure 1 The steps involved in the PATH method. Steps 3–6 are repeated for each combination of trade and operation that is studied on a given construction site

to determine the stages and operations of the construction process that are underway at a particular site. A narrative of each operation is obtained from engineers, supervisors and workers on-site. A description of the tasks and activities performed in each operation by each trade is obtained through worker interviews and direct observations. The weights of commonly handled tools and materials are ascertained at this time. The PATH data collection sheet is then customized for coding these tasks, activities and tools.

To carry out data collection, each observer selects a number of workers (preferably a crew) performing the same operation. The crew is usually followed for 3 or 4 h during each sampling period (from beginning of shift to break or from break to end of shift). Observations are made at fixed intervals of usually 45 or 60 s. Forty-five s is the minimum interval used that maintains reliability. The specific worker for each observation is randomly determined from those selected for analysis at the start of the day. The task in which the specified worker is engaged is recorded, along with PATH data, at each observation. This random sampling of workers and tasks allows simultaneous observation of the proportion of time that workers in a specific trade perform each task during a specific operation, as well as the frequency of exposures in each task.

The fixed interval sampling maximizes the number of samples per sampling period, while the random sequencing of workers prevents bias (e.g. over-sampling of workers engaged in a particular activity). Alternatively, random-interval sampling of a single worker could be employed, but this approach was thought not to be as efficient or as representative. If a single worker was followed during each sampling period, the total sampling time would have to be increased in order to capture inter-worker variability. Conversely, if a shorter sampling period was used to observe a single worker, the estimates obtained would less likely be

Table 1 Stages in the highway construction process and some representative operations*

Stage	Representative operations
Earthworks	Clear and grub Demolition Rodent control Excavation Dredging Embankment Grading Borings
Drainage	Basins, manholes and inlets Culverts, drains and pipes Rip rap Waterways
Water systems	Water systems
Paving, etc.	Subbases Dust control Shoulders Pavement Patching Berms
Curb and edging	Curb and edging
Highway guard, fences and walls	Highway guard Concrete barrier Fences and gates Field stone masonry
Incidental work	Sidewalks, ramps and driveways Soil handling Seeding, sodding and fertilization Trees, shrubs and groundcover
Traffic control devices	Boxes and foundations Service connections Traffic control signals Highway lighting Traffic signs Pavement markings
Structures	Cement concrete masonry Prestressed concrete beams Driven piles and sheeting Treated timber Structural steel Waterproofing Metal bridge railings Bridge structure

*Adapted from Massachusetts Highway Department (1988)

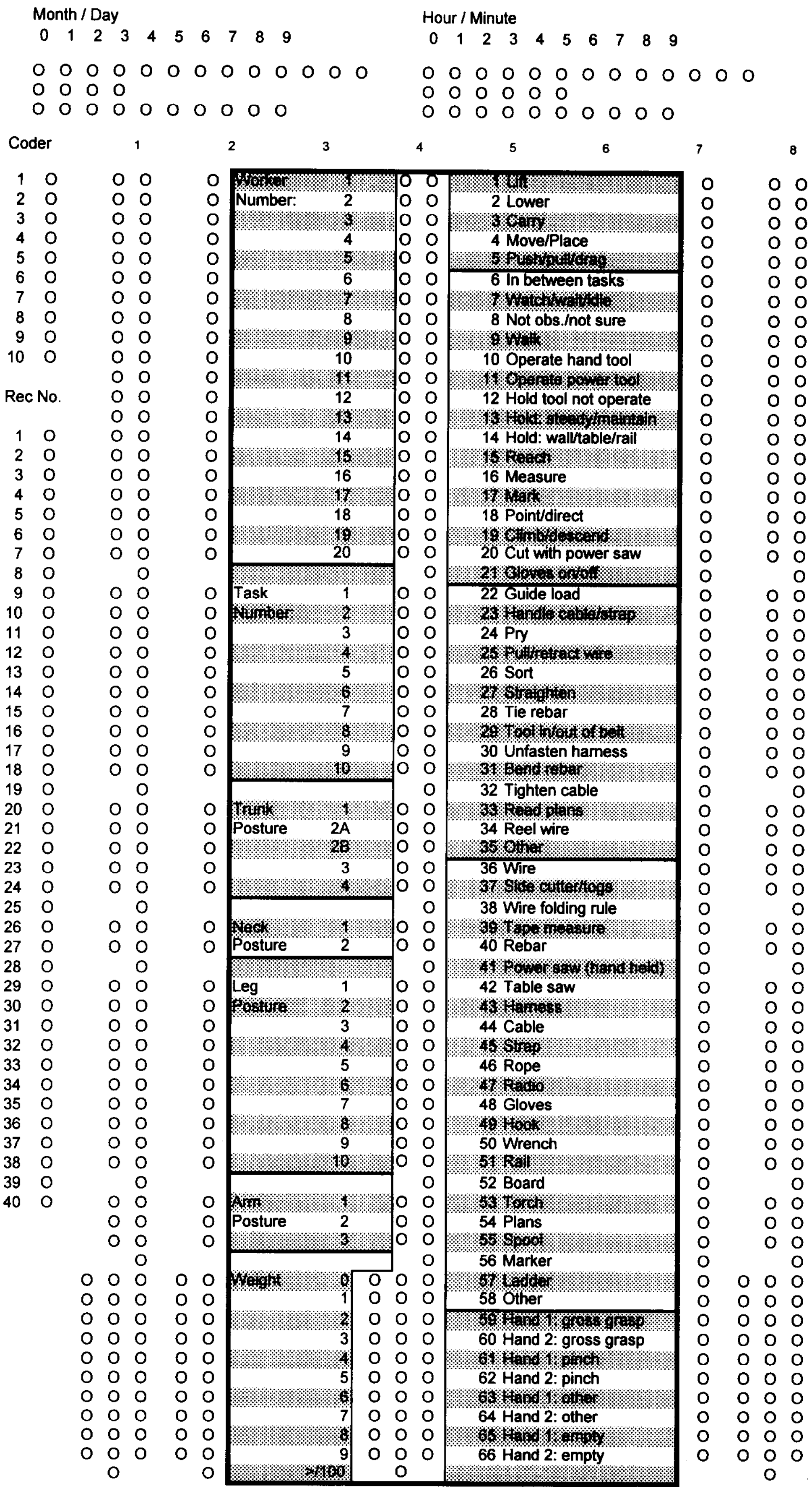

Figure 2 A PATH data coding sheet and a sample template that was developed for iron workers tying re-bar. The coding sheet is a standardized 'bubble' form that is scanned directly into a personal computer using optical mark recognition software (Remark Office OMR, Principia Products, West Chester, PA) and is 8.5″ × 14″ (21.6 cm × 35.6 cm) in actual size. The template, which is custom-designed for use with each combination of trade and operation, moves across the coding sheet and is used to identify variables for coding. The top rows and left-most columns of the sheet are for general information: date and analysis start time, observer and project record number. The rest of the sheet is divided into eight pairs of

representative of the tasks and activities performed by all individuals in the crew or operation.

For each observation, the following PATH data are coded on a data collection sheet (*Figure 2*) which is customized for each combination of trade and operation:

Posture is coded as the orientation of four body segments (trunk, legs, arms and neck). Posture codes in the PATH method are modifications of those found in OWAS (Karhu *et al*, 1977; 1981). Definitions of these codes are shown in *Figure 3*. Since Punnett *et al* (1991) found a higher incidence of low back disorders with severe flexion than with moderate flexion, trunk posture was modified to include two levels of forward flexion: moderate and severe. Neck posture codes, which were not included in the original OWAS method, were added because it was thought that construction workers have an increased risk for WMD of the neck. Neck posture is presently coded as either neutral or non-neutral because of low inter-observer agreement when additional codes were used (see Validity and Reproducibility section below). Three leg posture codes were added to the seven codes in the original OWAS method because they are commonly seen in construction. The added codes are: sitting on the floor, crawling and legs not fully supporting the body (e.g. use of a harness). Arm posture codes are identical to those used in OWAS.

Activities are the fundamental acts that are required to complete a task. Many of the activity codes are based on work elements (e.g. reach, grasp and move) taken from the time study methodology traditionally employed by industrial engineers (Barnes, 1980). Activity is a sub-division of task, so that a shoveling task may include activities such as shovel, carry and throw. Because activity is task-dependent, separate activity codes are determined *a priori* for each combination of trade and operation. There are activity codes for whole-body exertions, gross-motor exertions and fine-motor exertions; more than one activity may be coded for each observation. Activity is subdivided into four categories:

(1) manual material handling activities,
(2) activities that are common to most trades and operations,
(3) trade/operation specific activities and
(4) hand postures/activities.

Tool use is also task-dependent and a list of tools for each combination of trade and operation is generated before data collection.

Handling is recorded as a load and uses the actual weight of a tool, part or piece of material whenever possible. The load handled is ascertained prior to PATH sampling in one of two ways: (1) by direct measurement of the tool or object weight with a force gage or (2) by accessing standard construction material data.

The observed frequencies of specific postures, activities and loads provide estimates of the proportion of time that workers are exposed to each of these factors. Ninety percent confidence intervals are also calculated (Pape, 1991). Obstructed views are excluded from the analyses.

Inter-observer agreement is checked for each new operation that is studied. Statistical power calculations provide the number of observations needed to satisfy a pre-determined confidence interval for the frequency of any specific exposure. Preliminary data can be used to estimate the proportion of exposure time for each variable, updating this estimate as data are collected. In practice, sample size is often constrained by logistical considerations.

The estimates of the proportion of time that workers devote to various postures, activities and handling loads during different construction tasks can be used to identify both the frequency of hazardous exposures for an entire operation, as well as hazardous activities within tasks. Observations may be stratified by external factors (e.g. day of the week, the weather, etc.) to determine whether these factors affect the frequency of exposures under study.

Observer training

The PATH training procedure has been standardized over multiple training sessions. This has resulted in the development of a 30-h training curriculum and manual (Construction Occupational Health Project, 1995), which includes numerous exercises, practice coding sheets and templates, a two-dimensional mannequin and other visual aids.

First, an overview of the construction taxonomy and PATH method is presented. Next, the trainees learn the PATH posture codes. Trainees begin to code postures from still photographs, followed by video in which the frames at the times of observation are frozen for 5 s, and then coding of the video is performed in real time. Trainees then go to the field and code construction workers directly in real time. During the real-time coding, trainees code workers simultaneously with experienced observers, so that inter-observer agreement can be evaluated.

Validity and reproducibility

Early in the development of the PATH method, the PATH posture codes were tested for validity and reproducibility. Validity of the PATH trunk posture codes was determined by comparing results from the PATH analysis to results obtained using simulated real time analysis (Keyserling, 1986). Validity for the other posture codes has not been evaluated. Intra-observer agreement was evaluated using videotape matched in time with field oservations and inter-observer agreement was measured in the field. As with any observational method, validity and reproducibility depend in

columns each of which represents a single observation. The columns are separated into 'fields', which are groups of bubbles that are scanned together. The left column contains fields for: worker, task, the posture of each of four body segments and load handled which is coded as the actual weight of a tool, part or piece of material. The right column is a single field which is subdivided into five sections for the ease of the observer: (1) manual material handling activities, (2) activities that are common to most trades and operations, (3) trade/operation specific activities, (4) trade/operation specific tools, (5) hand postures/activities

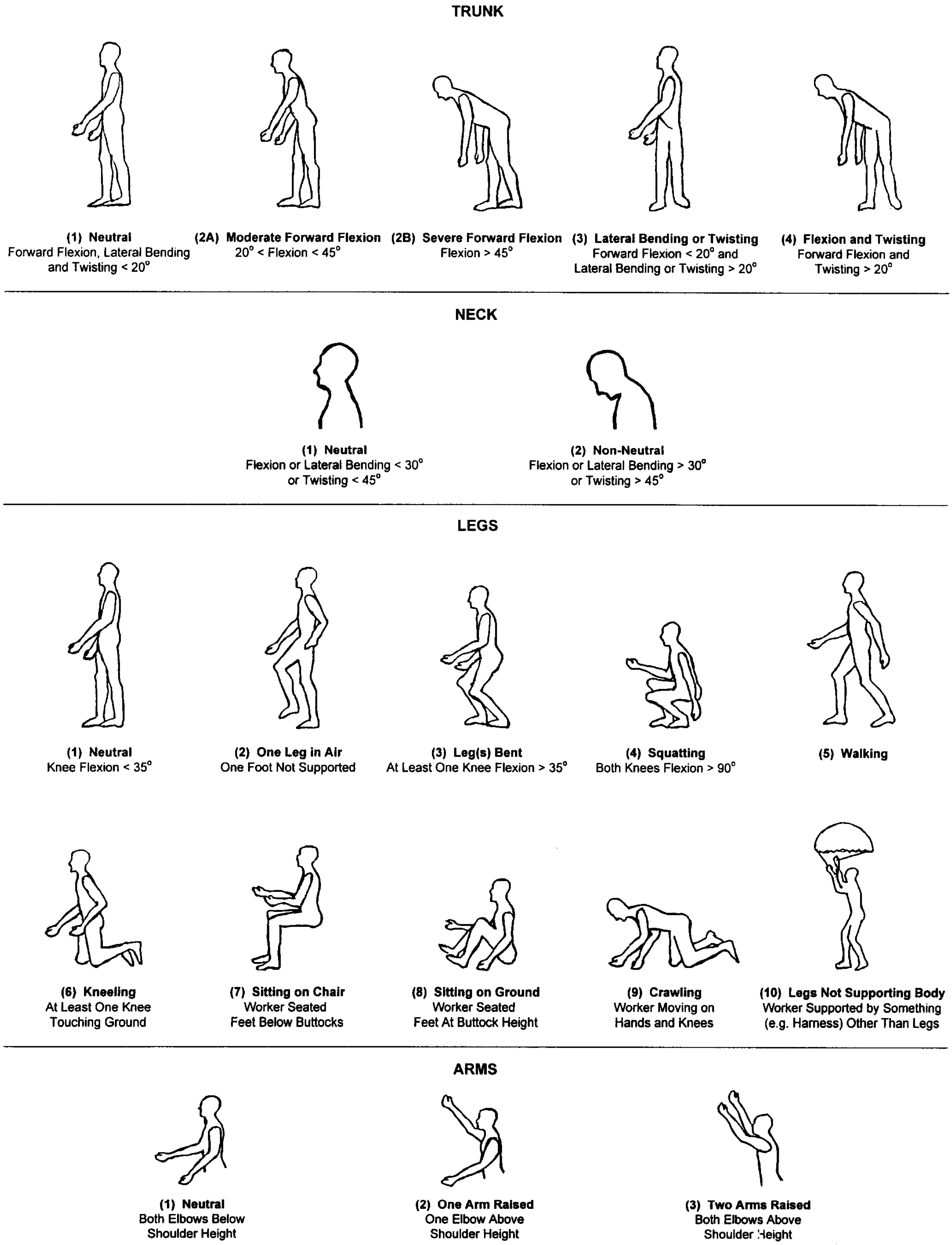

Figure 3 Definitions for the PATH posture codes. The PATH posture codes are modified from OWAS posture codes (Karhu *et al*, 1977)

part on the skill, experience and specific training of the observers.

Validity

The simulated real time analysis method developed by Keyserling (1986) for recording the postures of the trunk and shoulders employs a playback of a videotape in 'simulated real time'. A personal computer is used in this analysis and each posture category is assigned to a specific key on the computer keyboard. When the worker changes posture the analyst hits the appropriate key on the keyboard. The internal clock of the computer is used to keep track of the time when posture changes occur.

Two 1-h sections of videotape that were recorded while PATH data were collected in the field were used in this analysis. One section was a collection of work segments of laborers performing manual material handling activities; the other was a collection of segments of carpenters building forms. The simulated real time method was programmed so that appropriate keys for the PATH trunk posture codes were defined. The videotapes were viewed in segments of varying duration in order to provide vigilance breaks and to reduce keying errors. Estimates of the proportion of time spent in each of the PATH trunk postures were determined using both the PATH work sampling-based method in the field and the simulated real time method in the laboratory.

Posture durations estimated from the two methods were compared (*Table 2*). The largest differences in estimated times spent in each posture were: (1) a 24% difference in the estimated time spent in a neutral trunk posture for the carpenters and (2) a 21% difference in the estimated time spent in a moderately flexed trunk posture for the laborers. The differences for the laborers could be the result of slight differences in coding of the postures near the moderate–severe flexion border (45°). The differences in the carpenter data were thought to reflect a limitation in the experimental design. The simulated real time method estimated a large proportion of time in a neutral posture that appeared to be coded as either moderate or severe flexion with the PATH method. It is believed that this difference may be attributable to differences in real time field observations and simulated real time observations from videotape. The videotape presents only one view of the worker, which when not in the sagittal plane, makes trunk flexion difficult to see, whereas in the field the observer can move with the worker to maintain an optimal viewpoint.

Further studies of validity are planned for the trunk and other posture groups. These studies will employ either electrogoniometers/inclinometers or marker-based motion analysis systems for direct measurement of posture and/or motions. By removing errors in the method used for comparison, a more accurate measure of the validity of the PATH observations can be determined.

Intra-observer agreement

PATH posture data collected in the field in real time were compared to PATH posture data coded by the same observer in the laboratory from videotapes recorded during the field PATH analysis. The PATH analysis of the videotape was performed as the tape was played in real time. The videotape was prepared with a verbal signal on the audio channel that allowed the sampling occasions to be matched almost exactly in time. This was also the same videotape that was used in the validity analysis. The arm and leg postures showed excellent agreement for the two data sets, with the proportion of agreement greater than 0.90 for the pooled data (*Table 3*). Neck and trunk postures showed less agreement, with the proportion of agreement for the pooled data 0.65 and 0.73, respectively. At the time of this analysis, four neck codes were used: (1) neutral, (2) flexed, (3) laterally bent and (4) twisted. Observers have reported that they found it difficult to distinguish between the three non-neutral neck codes, so these have subsequently been reduced to one. The lower agreement for trunk posture was again attributed to the difference between observations made in the field and those made from videotape, as discussed above.

Inter-observer agreement

Inter-observer agreement for the PATH posture codes has been evaluated throughout the method's development and continues to be evaluated with each new combination of trade and operation that is studied. Although 100% agreement is always desired, it is

Table 2 Validity of PATH trunk posture codes

	Proportion of time in specified trunk posture PATH observations compared to simulated real time analysis*					
	Laborers		**Carpenters**		**Pooled**	
Trunk posture	**Path $n = 60$**	**Simulated real time†**	**Path $n = 59$**	**Simulated real time†**	**Path $n = 120$**	**Simulated real time‡**
1 – neutral	0.34	0.28	0.34	0.58	0.34	0.42
2A – moderate flexion	0.16	0.37	0.10	0.03	0.13	0.20
2B – severe flexion	0.33	0.17	0.22	0.09	0.28	0.13
3 – twisted	0.07	0.03	0.24	0.16	0.15	0.09
4 – bent and twisted	0.10	0.15	0.10	0.14	0.10	0.15

*Keyserling (1986)
†From 1 h of videotape matched with field coded PATH data
‡From 2 h of videotape matched with field coded PATH data

Table 3 Intra-observer agreement of PATH posture codes

Proportion of agreement for postures of four body segments field coding vs matched coding from videotape			
Body segment	**Laborers** $n = 60$	**Carpenters** $n = 59$	**Pooled** $n = 120$
Trunk	0.75	0.70	0.73
Legs	0.88	0.97	0.92
Arms	1.00	0.93	0.97
Neck*	0.69	0.63	0.65

*Four neck codes

Table 4 Intra-observer agreement of PATH posture codes

Two carpenters building forms		
Body segment	**# Observations**	**Inter-observer agreement**
Trunk	42	0.61
Legs	42	0.73
Arms	42	0.78
Neck*	42	0.29

*Four neck codes

Table 5 Intra-observer agreement of PATH posture, activity and grasp type codes

Two laborers laying pipe		
Body segment	**# Observations**	**Inter-observer agreement**
Trunk	79	0.82
Legs	79	0.81
Arms	80	0.99
Neck*	79	0.54
Activity	84	0.79
Grasp type†	158	0.87

*Four neck codes
†Two grasp type codes per observation (right and left hands)

impossible to synchronize observers in the field to within a fraction of a second and workers do change posture that quickly. For the PATH codes, a proportion of agreement between observers of 0.8 was set as the criterion for beginning data collection.

Early in the development of PATH, inter-observer agreement was evaluated using simultaneous samples that were collected by two observers in real time in the field observing carpenters building forms. The proportions of agreement between observers for postures at each body segment are shown in *Table 4*. None of the values in this analysis met the 0.8 inter-observer agreement criterion. Some of the coding errors were thought to be due to lack of synchronization between the two observers and others due to imprecisely defined posture coding rules.

After redefining the posture codes more precisely and developing an accurate method for synchronizing observers, inter-observer agreement was measured again as part of the pilot study that is described below. The data used in this analysis were collected during observation of two laborers assisting in a pipe-laying operation. The proportions of agreement between observers for each body segment, as well as for activity and grasp type codes are shown in *Table 5*. For the most part, these values meet the acceptability criteria. The notable exception is for neck posture. Because of low inter-observer and intra-observer agreement for neck posture, the number of neck codes was reduced to two: (1) neutral and (2) non-neutral (see *Figure 3*).

A PATH pilot study: laborer activities in drainage operations

Introduction

In this pilot study, PATH data were collected by two researchers on five occasions from a union highway construction site in Plymouth, MA. The data were used to estimate the proportion of time that construction laborers spent in awkward postures, handled loads and performed activities in various construction operations during the drainage stage. The goals of this pilot work were to assess the utility of the PATH method and to obtain an initial characterization of the ergonomic features of laborers' work.

Methods

During the first site visit, the stages and operations of construction work that were in progress were obtained from the site's field engineer. The drainage operations chosen for study were: (1) pipe-laying, (2) rip-rap construction, (3) catch basin installation and (4) clean-up. Descriptions of each operation, and the tasks performed by laborers in each, were compiled through field observations and worker interviews (*Table 6*). PATH data coding sheets were developed to include the activities performed and tools used by the laborers during each operation. The tools and materials handled by the laborers were weighed with a force gage.

The number of observations for each worker performing each operation during each day was quite variable. This was because there was a small number of laborers working at the construction site and they performed whatever operations and tasks were required to be completed during each day. During the first two days of field work the two observers examined the same workers simultaneously, so that inter-observer agreement for posture coding could be examined (see *Table 5*). On the remaining three days, the observers collected PATH data independently. PATH data were collected at 45-s intervals over sampling periods ranging between 15 and 45 min. A single worker was sampled for the duration of each period. A total of 885 observations was collected for six laborers during four operations in the drainage stage of highway construction.

Results

The laborers spent large proportions of time in non-neutral trunk postures, with exposures to different trunk postures varying among operations (*Figure 4*). The proportion of time that laborers spent in non-neutral trunk postures during each operation also varied among workers and days (*Figure 5*). The laborers handled light loads (often tools) for much of

Table 6 Description of tasks performed by laborers in the four operations studied

Stage	Operation	Description of major tasks in each operation	Description of tasks performed by laborers in each operation
Drainage	Pipe-laying	A trench is dug. Sections of pipe are laid in the trench, mortared and connected. The trench is then back-filled. An excavator is used by an operating engineer to perform the major tasks.	Laborers perform shoveling activities, mortar pipe sections together and compact the soil after back-filling.
	Rip-rap construction	Rocks are dumped at the end of a drainage pipe and spread over the ground by laborers.	Laborers construct the rip-rap structure by manually placing the rocks in proper locations.
	Catch basin installation	Catch basins and frames are secured to the drainage system.	Laborers handle catch basins and frames, and mortar these to the drainage system.
	Clean-up	Waste generated during the operation is removed and tools are stored.	Laborers perform housekeeping activites, e.g. sweep, shovel debris, move trash barrels and store tools.

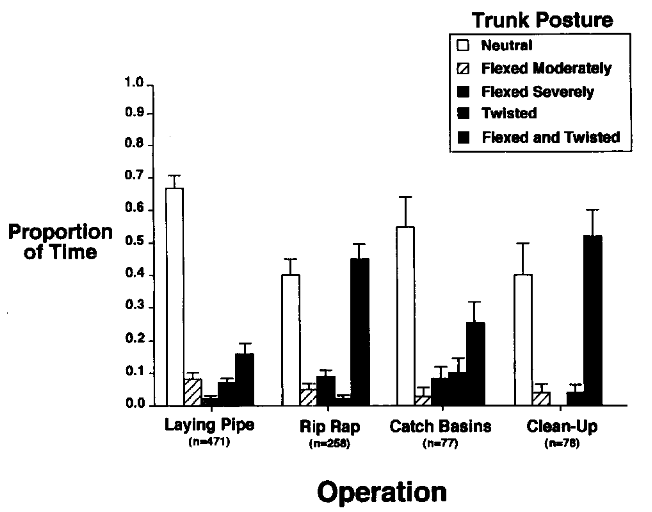

Figure 4 Trunk postures of laborers for four different operations. Mean estimates of the proportions of time laborers spent in each posture along with 90% confidence intervals (error bars) are shown

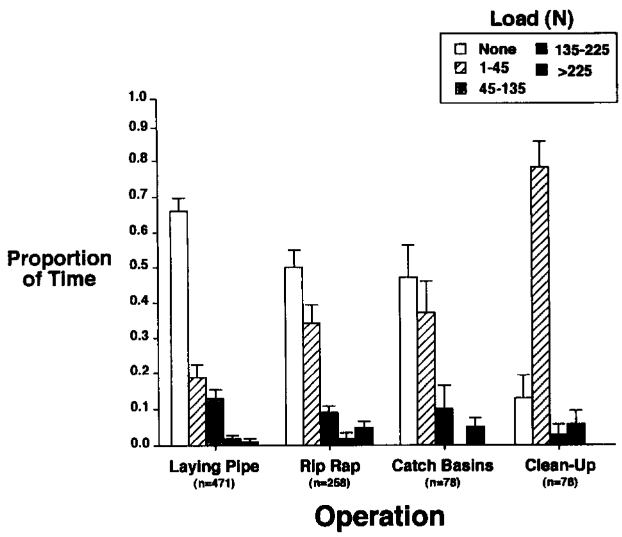

Figure 6 Loads handled by laborers for four different operations. Mean estimates of the proportion of time laborers handled loads in various categories along with 90% confidence intervals (error bars) are shown

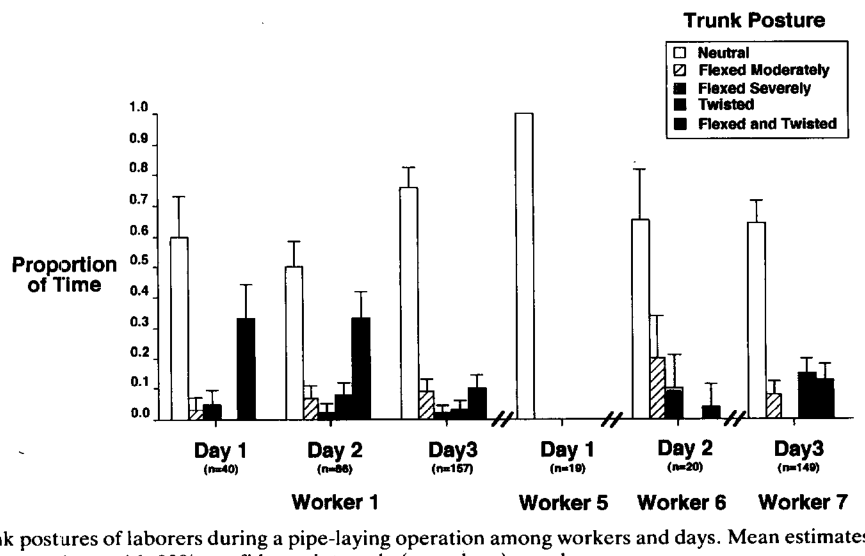

Figure 5 Variation in trunk postures of laborers during a pipe-laying operation among workers and days. Mean estimates of the proportion of time laborers spent in each posture along with 90% confidence intervals (error bars) are shown

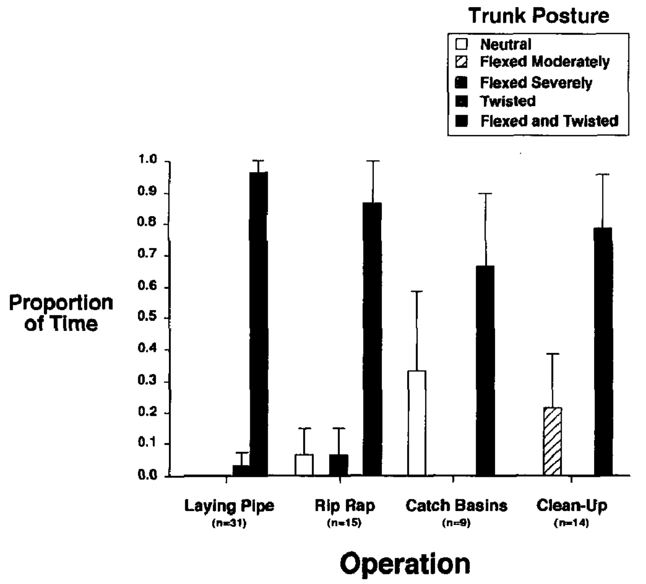

Figure 7 Trunk postures of laborers while shoveling for four different operations. Mean estimates of the proportion of time laborers spent in each posture along with 90% confidence intervals (error bars) are shown

the working day. As with postures, loads handled also varied among operations (*Figure 6*). Loads estimated to be greater than 225 N (50 pounds) were handled in all operations except clean-up, although infrequently.

As expected, the activities of laborers varied greatly among operations. Workers performed manual material handling activities between 10 and 41% of the time in each operation. The most common construction activities were shoveling, sweeping and cutting. On the other hand, exposures to ergonomics hazards during a *single* job activity appeared to be fairly consistent, regardless of operation. For example, while shoveling, workers spent over 70% of the time with their trunks bent and twisted in all the observed operations (*Figure 7*).

Conclusions

The results of the pilot study indicate that construction laborers spent a large proportion of time in non-neutral trunk postures and have low to moderate manual material handling demands during drainage operations. This study was limited by a small number of workers and construction operations. The inter-worker and inter-day variability of exposure indicate that a greater number of workers must be sampled on a greater number of days before the results can be considered representative of similar construction operations and job activities. Nevertheless, the results of this pilot study demonstrate how PATH analysis can be used to identify specific operations and job tasks posing ergonomic hazards.

Discussion

Despite the fact that construction work has been found to result in a high prevalence of musculoskeletal disorders, there is little quantitative information on the ergonomic hazards of this work. The PATH method was developed to assist in the filling of this gap by quantifying worker postures, activities, tools used, loads handled and grasp type. The method employs a work sampling-based approach, so that the non-repetitive nature of construction work is captured. Because of the fluidity of the workplace and the mobility of the work force within the workplace, the method was designed so that observers also had a high degree of mobility. The method can also be adapted for use in other industries having large proportions of non-repetitive or irregular work, such as mining or agriculture.

The PATH method is designed to allow easy customizing for each trade/operation combination that is studied. The frequency of tasks within each operation is observed directly. Results can then be stratified at the operation or task level. The average proportion of time that workers are exposed to each risk factor during a specified task could also be used in combination with worker self-reports of the proportion of time spent performing each task in order to estimate that worker's exposures for use in an epidemiological study. By performing both pre- and post-evaluations, the method could also be used to assess the effectiveness of interventions designed to reduce ergonomic hazards.

From preliminary analyses it appears that the PATH method will be found to be reasonably valid and reliable. Observers require about 30 h of training to code with at least 80% agreement with an experienced observer. Further tests of validity, using methods that can accurately assess worker posture, are planned.

Though sample sizes are often constrained by practical considerations, it is important to remember that a small sample will result in large confidence intervals. The results may also be biased by poor selection of sampling period. This is especially important in construction where sampling long and/or irregular cycles over a short period of time may result in an incomplete and unrepresentative description of exposure. The task-based approach in which PATH data are collected helps to address this, but the variability of exposures within a task and among workers needs to be determined both for epidemiological studies and to target interventions effectively.

The PATH method is well suited for characterization of ergonomic risks to the lower extremity, back, neck and shoulders. It does not characterize ergonomic exposures to the distal upper extremity, because of the difficulty in viewing, and recording postures and motions of the hand and wrist. For hand-intensive activities, such as tying concrete reinforcement (rebar), a more detailed analysis that is capable of producing a semi-continuous recording of hand and wrist posture, and hand force should be employed, in addition to the PATH analysis.

The PATH method appears to be an effective and efficient method of collecting ergonomic hazard data for many operations and tasks in the construction industry, as well as non-repetitive tasks in other industries. In the pilot study presented here, laborers in drainage operations were found to have frequent exposure to postural stress to the trunk. However, more data are needed to analyze the variability of ergonomic exposures for different workers, operations and job activities. Trades and operations currently being studied as part of this effort include: tilers installing wall tiles in a tunnel, carpenters building concrete forms and iron workers tying re-bar.

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