Final Performance Report

Alternative Ergonomic Job Analysis Methods for Manufacturing

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ABSTRACT

This study focused on the development and evaluation of new exposure assessment strategies for non-cyclic as and cyclic manufacturing jobs. New methods for the evaluation of ergonomic problems in special trades work and self-paced assembly work within a forging plant were developed. A work-sampling based approach was used to evaluate the postural and manual material handling requirements of millwrights work. Over 8,000 observations were made on 8 workers taken over 8 days to allow an assessment of the between worker and between day variability of exposures for this occupation. For the self-paced manufacturing jobs, a video-based ergonomic job analysis method was used to estimate the frequency of awkward postures, manual materials handling, average cycle times, and estimated rest allowance for different muscle groups. One-hundred eight video recordings of approximately 10-15 cycles were made on three workers of two different occupations for up to 3 times per day on approximately 10 days to allow an assessment of inter-worker and inter-day variability of each of the ergonomic exposures. Analysis of variance was used to estimate the inter-worker and inter-day components of variability for both the skilled trades and self-paced manufacturing jobs. Bootstrapping, a statistical re-sampling method, was used to examine the reliability of different exposure assessment strategies so that recommendations could be made about the appropriate use of the alternative exposure assessment methods. The recommended strategies were then pilot tested on a third self-paced manufacturing job for which 45 videos were recorded to provide a preliminary assessment of the generalizability of the results. Key findings of the study included:

- Exposure variability across workers of the same occupation was large among those included in this study. Therefore, epidemiologic studies that use occupation as a proxy for exposure estimation may result in significant random misclassification of exposure, at least for the types of occupations studied here.

- Results of the analysis of variance for Millwrights work demonstrated that the manual material handling requirements were fairly low, but the frequencies of awkward trunk, arm and leg postures were high and variable across workers and days. Bootstrapping analysis suggested that groups of workers should be sampled for multiple days (e.g., >6) for a reliable estimate of average exposure to awkward postures.

- Results of the analysis of variance on the self-paced manufacturing jobs demonstrated that there was large variability among workers and over time for many of the ergonomics exposures. Assessment strategies used in research or practice that involve observing one individual for limited time periods are likely not to provide reliable estimates ergonomic exposures over the long term.

- For both types of work studied, strategies required for the reliable estimate of exposure will differ across exposure variables since of the sources of exposure variability are not the same across exposure variables. For example, for the self-paced manufacturing work, the contribution of inter-worker variability tended to be higher for the estimation of required rest allowance for different muscle groups than for exposure to trunk flexion or repetition for the self-paced manufacturing jobs. As a result, more workers may be needed for a reliable estimate of required rest allowance than for the other exposure variables considered in this study.

- For self-paced manufacturing work, the collection and analysis of at least 3 different videos recordings of at least 10 cycles taken on different days and on different workers was recommended as the most efficient (i.e., fewest videos for a reliable assessment of exposure) among those strategies tested in this study. This finding was supported in the analysis of the third self-paced manufacturing jobs.

Attempts to find associations between the exposure data collected in this study and health outcome data (i.e., injury rates and muscular discomfort) were unsuccessful due limitations in statistical power (exposure measurements were only available for only a few occupations) and due to poor quality of the forging plant's health surveillance data.

SIGNIFICANCE OF FINDINGS

Current ergonomics research and practice activities too often rely on exposure surveillance efforts that lack precision and reliability necessary to advance our understanding of exposure-response relationships and the effects of ergonomic interventions on exposure levels. The ergonomic job analysis methods and data collection strategies developed and tested in this study have the potential to improve the precision and reliability of job analysis efforts currently used in practice and in research in the automotive and other industries. Such methods are needed for evaluation of the impact of ergonomic interventions on exposure profiles for research and practice.

USEFULNESS OF FINDINGS

The ergonomics practice of evaluating ergonomics problems in industry often involves the use of checklists that are completed via observations of the work practices taken over a relatively brief period. The findings of this study suggest that such practice will not provide a reliable estimate of various ergonomics risk factors. The findings of this study provide ergonomics researchers and practitioners with information that can help guide in the reliable assessment of ergonomics risk factors that can be used in epidemiologic study, the prioritization of ergonomic problems within a facility, or in the evaluation of ergonomic interventions.

SCIENTIFIC REPORT

Background

MSDs are impairments generally characterized by chronic pain and discomfort that impair and eventually damage the nerves, tendons, tendon sheaths, muscles and blood vessels. These disorders include nerve compression disorders such as cubital tunnel syndrome, carpal tunnel syndrome, and thoracic outlet syndrome, as well as inflammations of the tendons and sheaths such as tendinitis and tenosynovitus. Low back pain is among the most severe and costly of the disorders.

The Bureau of Labor Statistics (1998) reported that there were almost 2 million lost-time injury and illness cases in 1996, with overexertion was the most frequently recorded direct cause. The annual direct and indirect costs of MSDs are estimated to be in the tens of billions of dollars (NIOSH, 1996). Even with the observed decline of these injuries since the early 1990s, MSDs are still an important problem for many occupations.

Generic risk factors related to work that are cited include heavy manual materials handling, highly repetitive motions, sustained awkward postures and static muscular contractions, vibration, temperature extremes and mechanical stresses. Numerous studies have documented associations between the physical requirements of work and MSDS. MSDs have been linked to loading of the neck/shoulders (e.g., Hagberg, 1986; Stenlund, Goldie, Hagberg, and Hogstedt, 1993; Westgaard, Waersted, Jensen, et al., 1986), repetitive or forceful hand exertions (e.g., Kurppa, Viikari-Juntara, Kuosma, et al., 1991; Roto and Kivi, 1984; and Silverstein, Fine and Stetson, 1987), loading or contact stresses on the knees (e.g., Felson et al., 1991; Thun, Tanaka, Smith, et al., 1987) and loading on the low back (e.g., Kelsey, Githens, White, et al.,1984; Marras, Lavender, Leurgans, et al., 1993).

In an analysis of the epidemiologic evidence, Bernard (1997) concluded that there was substantial evidence for exposure to awkward postures and neck/shoulder disorders, a combination of physical work factors and disorders of the elbow, hand/wrist and tendonitis, and heavy lifting and low back disorders. In an evaluation and discussion of a broader set of studies, members of the Steering Committee for the Workshop on Work-Related Musculoskeletal Injuries conducted by National Research Council (1999) concluded that for "those studies involving the highest levels of exposure to biomechanical stressors of the upper extremity, neck and back, and for those with the sharpest contrast among the study groups, the positive relationship between the occurrence of musculoskeletal disorders and the conduct of work is clear".

Despite these conclusions, no clear exposure-response relationships can be drawn easily from the research. Without an improved understanding of exposure-response relationships, the effective design of interventions intended to reduce MSDs is extremely difficult. This problem is at least in part due to the general lack of information available on frequency, intensity and duration of exposure for individuals over long time periods. As mentioned earlier, causes of MSDs are also multifactorial, making the measurement of all potential contributing factors quite challenging. The evaluation methods developed and evaluated in this research project will focus on those related to the physical requirements of the work.

Job title or occupation is the most a common surrogate for exposure in epidemiologic studies (Burdorf, 1993; Hagberg, 1992). Such a surrogate for exposure when there is a large variability in exposure within occupations can lead to exposure misclassification and bias the risk assessment of the exposure when occupations are compared to one another. Observational methods and direct measurements have been used, although much less often, to characterize the physical characteristics of jobs in epidemiologic studies (Burdorf, 1993).

Two conceptual models that provide useful starting points for understanding the pathology of MSDs include external exposures that influence internal dose (or load) within the body, and mechanisms for adaptation or impairment that affects an individual's capacity and possibly lead to MSDs (Armstrong, et al., 1993; NRC, 1999). It follows that exposure assessment methods that take into account the physical requirements of the job in terms of intensity, duration and pattern of exposure and an individual's physical capabilities could be extremely valuable. Take, for example a job for which an individual experiences localized muscle fatigue build up, which is related to both the external exposure to physical loading and the individual's capabilities. This fatigue build-up will reduce muscle capacity, increase swelling and discomfort, and eventually lead to damage of tissue fibers. A job that requires physical activity without adequate work-rest schedules will result in a localized muscle fatigue build-up that most likely accumulates exponentially throughout the shift (Konz, 1998a, 1998b).

In industry, injuries and illness are also often categorized by department or job classification, rather than direct measurement of exposure. This approach allows an organization to identify the departments or jobs that need special attention in terms of reducing MSD experience, but provides no information on which factors are contributing the problems. In order to obtain exposure information for a job on a variety of physical and environmental factors, the use of an observational checklist approach to job analysis has been used in manufacturing settings. Such an approach is relatively inexpensive and allows many potential risk factors to be evaluated quickly. However, observational approaches that employ the use of checklists generally require the observer to rate relatively broad categories of exposure and are susceptible to random and systematic error. While these approaches are recognized as quite useful for the prioritization of jobs in terms of their problems, it is not clear as to whether these instruments can detect moderate changes in exposure when an intervention is introduced to the work setting. The development and evaluation of methods used to characterize the physical characteristics of work accurately is needed for intervention research (Hagberg, 1992; Winkel and Mathiassen, 1994).

Many of the jobs in automobile manufacturing are physically demanding, associated with risk factors such as awkward postures of the trunk and upper extremities, repetitive upper extremities motions and frequent manual materials handling (e.g., Engstrom and Medbo, 1997; Lavender, Oleske, Nicholson, et al., 1997; Punnett, Fine, Keyserling, et al., 1991). Forging is perhaps one of the most physically demanding industrial processes in this industry. For example, many jobs in forging work can be characterized by heavy MMH and frequent use of long hand tools (e.g., tongs used to remove stock from furnaces) that produce large moments on the joints of the upper extremities and low back.

A number of intervention research activities have been performed to evaluated workplace changes designed to reduce ergonomic exposures or improve the general health of employees designed to reduce employee risks of MSDs. Field and/or laboratory studies have been performed to evaluate the effects of tools (e.g., Degani, et al., 1993; Ortengren, et al. 1991; Sen and Sahu, 1996), work methods and area design changes (e.g., Buchholz and Paquet, 1998; Luttmann, et. al., 1991; Reynolds, et al., 1994), and exercise programs (e.g., Silverstein, et al., 1988). More recently, macro-ergonomic evaluations to evaluate the effectiveness of new sociotechnical systems (work organization) or ergonomics programs on injuries and illnesses have also been performed (e.g., Drury et al., 1998; Westlander and Viitasara, 1995). Interventions that have been evaluated in the automotive industry include the redesign of job tasks (e.g., More, 1994), job task rotation (e.g., Van Velzer, 1992), and workstation redesign and joint labor-management programs (e.g. Keyserling et. al. 1993). Many studies involving interventions are limited to the evaluation of changes in ergonomic exposures and changes in related injuries or illnesses, productivity or product quality remain unmeasured. These factors are essential for a comprehensive evaluation that will allow the benefits to both the employer (i.e., cost savings) and employees (i.e., decreased risk of injury). The measured change in the risk aftor pre- and post- intervention allows researchers to help determine why an intervention worked or did not work, and could possibly provide new information on the relationship of certain risk factors and MSDs.

Significance

While much health-related research has been performed in many sectors of the automobile industry, the evaluation of ergonomic risk factors and intervention research in forging has been given very little attention, to date. Even less attention has been given to skilled trades work (e.g., electricians, machine repair) in automobile manufacturing, who comprise a significant proportion of the workforce. This research project will provide new information on ergonomic exposures and intervention efforts that have not been examined in previous studies involving this industry.

Most methods for evaluating ergonomic exposures in practice and in research assume that the work is cyclical, having little variability over time, and therefore exposures over short periods are thought to be indicative of those over long periods. This is generally not a valid assumption as the physical demands of even highly routine assembly jobs may change, for example, with delays in the industrial process and changes in individual work methods throughout a shift. There is a need to understand the important sources of exposure variability for both in production work and in skilled-trades work in order to develop reliable exposure assessment strategies. The strategies developed in this study can be used to refine exposure assessment efforts used in both epidemiologic and intervention research of manufacturing facilities.

This study considered approaches to exposure assessment and intervention evaluation that have received relatively little attention, to date. In the automobile industry, perhaps the most common method of ergonomic job analysis involves rating exposure levels using an industry checklist. Use of such a checklist fails to capture the variability of ergonomic exposures over time and across workers, and therefore is perhaps most appropriate for repetitive jobs in which exposures change very little from work cycle to work cycle. In this study, a work-sampling based ergonomic job analysis approach was employed to estimate exposures to individuals in special trades work within the automobile industry. A different non-traditional approach to ergonomic job analysis in automobile manufacturing was also applied to self-paced manufacturing jobs. A video-based method that provided quantitative estimates of load handling and exposures to awkward postures, as well as data in a muscular-fatigue accumulation model was used. The use of the muscular fatigue model was thought to have more promise than often used observational checklist type approaches since such an approach considers the capabilities of the employee, as well as the physical requirements and the temporal pattern of exposures. These factors are often lost in common checklist-types of job assessments, and are of particular importance in the evaluation of interventions such as job rotation (intended to reduce fatigue by altering patterns work), and work hardening (designed to enhance an individual's capabilities to perform the work), as well as the evaluation of engineering controls.

Preliminary Studies

Intervention research. Before the study, Paquet performed intervention evaluation studies in the construction industry, for which the incidence of MSDs is generally high and the physical ergonomic stressors are often great and extremely variable. After completing a job analyses to evaluate ergonomic exposures in a large highway construction project, Paquet and Buchholz (1996) worked with contractors and construction workers to design and evaluate ergonomic interventions intended to reduce the intensity and frequency of ergonomic exposures found in several highway tunnel finishing operations. The most common physical ergonomic exposures were heavy MMH, frequent non-neutral trunk postures, and static loading of the shoulders during over-head work. Interventions that were implemented and evaluated included the use of pulley and dollies to aid MMH, use of a hand tools designed to reduce pinch forces when handling construction material, use of wood support beams to reduce static loading of the shoulders during overhead work, and ergonomics training. Pre- and post intervention interviews regarding usability of interventions and observations of exposures were used in the evaluation of interventions.

Buchholz and Paquet (1998) also performed a more detailed pre- and post-intervention evaluation of an assembly line operation for which there was a high incidence of injuries to the musculoskeletal system over a short period of time. A systematic ergonomic job analysis was performed on each job to identify risk factors using a checklist-type approach. Several intervention ideas were developed and presented to the contractor. A second assembly line was designed that incorporated some of the recommendations, and an evaluation of the new line showed that 43% of the original hazards had been eliminated or reduced without slowing production or reducing quality.

Evaluation of Ergonomics Exposure Assessment Methods. The development of reliable and precise ergonomic exposure assessment methods is needed to improve the state of the knowledge in musculoskeletal epidemiology and intervention research (Winkel and Mathiassen, 1994). Prior to the study, Paquet performed several recent research activities devoted to the development, evaluation and refinement of observational ergonomic exposure assessment methods (e.g., Buchholz, Paquet et. al., 1996; Paquet, et. al., 1998, 1999). In on study, categories of body posture recorded with two checklist type observational work-sampling methods, were compared to measurements of body posture recorded with electrogoniometry and electroinclinometry that were synchronized with video recordings on subjects during simulated working conditions.

Exposure Assessment for Skilled-trades in Manufacturing. "PATH" (Posture Activities Tools Handling) (Buchholz, Paquet et al.,1996) has been designed specifically to allow statistically valid estimates of event frequencies (task specific exposures and tasks frequencies) for non-cyclical types of work, such as that performed by skilled-trades. PATH requires work-sampling procedures derived from industrial engineering methods (Pape, 1991) that involving the coding of body posture categories, activities preformed, tools used and loads handled by a worker at a specific instant in time. The posture codes are modifications of those found in the OWAS (Ovako Working Posture Analysis System) (Karhu et al., 1977, 1981). The activities, tools and handling categories are original and can be customized as needed for each workplace or trade to be evaluated.

PATH was initially developed for use in the construction industry, but the method has since been used by the PI and others in studies of dairy farming, retail stores and hospitals.

Exposure Variability and Exposure Assessment. In order to obtain a reliable estimate of average exposure for study groups, measurements could theoretically be taken on all workers in study group under a representative set of working conditions pre- and post- intervention. However, the use of detailed job analysis methods under such conditions is not logistically or economically feasible. Often measurements must be made on a sample of workers over a limited amount of time. The distribution, duration and content of the work tasks may vary greatly among individual and days therefore careful consideration must be given strategy used to obtain a reliable estimate of ergonomic exposures (e.g., number of people measured, length of measurement time). Punnett and Paquet (1996) evaluated the important sources of variability of various physical ergonomic exposures for three construction operations, found that the operation and job task performed were generally important predictors of exposure, and that the day-to-day variability of ergonomic exposures was very high. They demonstrated the need for a task-based exposure assessment strategy with assessments across multiple days to improve the reliability of the exposure estimates for this type of work.

Paquet (1998) used exposure data and computer re-sampling techniques to relationship between length of observation and reliability of the exposure measure. This procedure requires the construction of an empirical probability distribution by placing a probability of 1/N (where N is the number of measurements in the sample) at each of the original sample's points. A smaller sample (or set) of size n (where $n \leq N$) is then drawn with replacement from the empirical probability distribution. The resampling of the empirical probability distribution and calculation of a statistic (e.g., mean exposure) is then repeated many times and confidence intervals based on the results of the resampling procedure can be obtained directly from the simulation (see Mooney and Deval, 1993 for a more detailed description of bootstrapping). This approach allowed the length of observation time or number of observation periods needed for a reliable estimate of exposures during an automobile manufacturing work.

As a result, Paquet (2001) recommended that strategies that attempt to assess multiple exposures such as those observed with PATH on groups of construction workers should require observation periods of 6 to 10 days to obtain reliable estimates of exposure for all variables. Whether or not such a recommendation is generalizable to other types of jobs is unknown.

Objectives and Specific Aims of this Study

The major objective of the study was the development of reliable ergonomic exposure assessment methods and strategies for skilled trades work and cyclic self-paced assembly work in automobile manufacturing to aid epidemiologic research and ergonomic intervention evaluation. Attempts were also made to link exposure information to health and symptom outcomes for selected occupations within an automobile forging plant.

The original specific aims of the project were to:

1. Evaluate the MSD experience of an automobile manufacturing workforce retrospectively from 1994-2001 to identify departments and jobs that require special attention

2. Develop reliable and precise ergonomic job analysis methods for skilled trades jobs (non-cyclical skilled labor) as well as production line jobs for the effective evaluation of interventions in manufacturing plants

3. Determine whether or not the evaluation methods are predictive of musculoskeletal endpoints

4. Test different exposure assessment strategies (e.g., number of workers and measurement periods) to determine which offers the most reliable measurement of exposures

5. Pilot test the job analysis methods and strategies

Procedures and Methods

The study was completed at a forge facility that employed 722 union-represented workers. Approximately 15% of the workforce was female, and the mean age of the employees was 31 years. The plant operated five days per week on three shifts. Much of the work in the plant involved heavy manual labor that was often performed at high temperatures (e.g., exceeding 90° F).

The plant had a joint labor-management Ergonomics Committee that consisted of fourteen employees and included the plant manager, corporate and union safety representatives, ergonomics technician, medical staff and hourly employees. This committee met monthly to evaluate the status of the plants ergonomics program. Interventions designed to reduce workers' risks to MSDs included the use of MMH aids such as mechanical cranes and counter-balancing mechanisms, voluntary job rotation among employees, and a health center designed to improve employee fitness and to be used as apart of a rehabilitation program for those previously injured.

In an effort to strengthen their intervention evaluation procedures, members of this committee requested outside assistance. Paquet (PI) and Vena (Co-PI) worked with Committee members to develop procedures aimed at improving the effectiveness of the committee. This included improving health outcome surveillance, ergonomics exposure surveillance, and intervention development and evaluation practices.

Specific aim 1, "Evaluate the MSD experience of the workforce retrospectively from 1994-present to identify departments and jobs that require special attention" .

Prior to the study, the forging plant used only frequency injury (not rates) recorded on OSHA 200 forms to identify ergonomic and safety problems within the facility. An evaluation of injury and illness rates for the time period of October 1999 and August 2001 was performed for the facility. Originally, a longer time period (1994-2001) was intended for study, but the person-time information required to calculate the incidence rates during this period was not made available.

Payroll records (Oracle Reports) were used to determine the number of person-hours devoted to each department over the modified study period. These were cross-referenced with the OSHA 200 form data to allow calculation of the incidence rates by injury type and body area affected. Overall incidence rates were recorded for all cases and for occupational injuries involving time away from work. Incidence rates were also calculated for different types of injuries including amputation, carpal tunnel syndrom, fractures, laceration and punctures, and sprains and strains. Overall incidence rates were also stratified by body area affected, and were compared to industrial averages reported by the Bureau of Labor Statistics (2001).

Since the injury rates were found to be high in the plant, the Ergonomics Committee indicated that it wanted to prioritize problems in terms of the number of employees injured rather than by injury rate to potentially improve the environment for as many individuals as possible. In 2001, a descriptive analysis of injuries and resulting days away from work reported in the OSHA 200 forms between October 1999 and August 2001 was completed in order to identify departments with the highest frequency of injury. While the overall objective of the research project was to develop improved exposure assessment methods that could be used in a variety of situations, in order to address the concerns of the Ergonomics Committee occupations within the departments having the highest frequency of injury during the study period were selected for further study.

Specific aim 2, "Develop ergonomic job analysis methods that are reliable and precise for the effective evaluation of intervention research".

Over 20% of the hourly workforce in the plant consisted of skilled trades work and had the highest frequency of injuries of departmental units in the plant. Special trades work consisted of Electricians, Millwrights workers, Bricklayers, Painters, Machine repairers and Pipe fitters. Employees of these occupations generally perform non-cyclic work activities that cannot be evaluated reliably in terms of their ergonomic exposures with the conventional checklist approach often in the automotive industry. Use of a work-sampling methodology such as the PATH provided more precise estimates of some ergonomic exposures for this type of work.

The Millwrights trade was one of the occupations selected for study. In this plant, Millwrights were among the largest of the skilled trades and were responsible for preventive maintenance and machine repair, welding and cutting. This trade had the highest two-year prevalence of MSD injuries among the skilled trades work performed in the plant, and ergonomics and health and safety personnel confirmed that this group was considered to be at the highest risk for MSDs among the skilled trades workforce.

Two research assistants completed a task analysis on the Millwrights work to ensure that the work was non-cyclic and to collect information necessary for PATH. Millwrights workers performed a variety of tasks on the machines in the production line and a machine shop.

The research assistants were trained in job analysis and use of PATH. Two palm pilots (HP, Jornada 525) were purchased and programmed for data collection in the field. Data were collected directly into a hand-held Excel spreadsheet and downloaded to computer for analysis. This represented a significant improvement over previous data collection effort using PATH, which have typically required pen and paper with manual data entry on computer. The variables included:

- Job location (department within the plant)
- Date
- Employee Number
- Trunk posture (<20 degrees forward flexion, lateral bending or twisting, ≥ 20 degrees but < 45 degrees forward flexion, ≥ 45 degrees forward flexion, ≥ 20 degrees lateral bending or twisting)
- Arm posture (2 arms < 45 degrees from vertical, 1 or 2 arms ≥45 and < 90 degrees from vertical, 1 arm ≥ 90 degrees from vertical, 2 arms ≥ 90 degrees from vertical)
- Leg posture (standing with legs bent < 35 degrees, kneeling, squatting, walking sitting, other)
- Task (Repair hydraulic, repair drive, breakdown, re-assembly, maintenance, preparation activities, fabrication, other)
- Load handling (0-5 lb, 6-20 lb, > 20 lb.)
- Manual handling activities (lift, lower, carry move/place, push/pull/drag)

The inter-observer reliability of the "computerized" PATH method for the two research assistants for each of the ergonomics exposure variable categories was evaluated. For the reliability analysis, the research assistants made 108 observations simultaneously for Millwrights work on 3 different days.

An exposure assessment strategy was developed that required eight (out of a total of 32) Millwrights employees to be monitored on eight different days. For each day of observation, a research assistant attempted to make 360 observations on two Millwrights workers. The exposure assessment effort for this trade consisted of 8,286 observations on the 8 workers, and allowed a detailed analysis of inter-observer, inter-day and intra-day exposure variability.

The over-all and task specific exposure frequencies were calculated for different work locations, tasks, workers, and days. The descriptive analysis allowed the important sources of exposure variability for Millwrights work to be identified.

Video-based Methods for Self-paced Cyclic Production Jobs

A video-based exposure assessment method was used to provide quantitative estimates of various ergonomic exposures in two cyclic self-paced manufacturing jobs. The prerequisites for selecting the production jobs were that the occupation had at least three workers assigned to the same job tasks and workstation designs on the same shift, and that no job rotation across tasks or other jobs was taking place. Additionally, the occupations selected were from departments having among the highest frequencies of injuries as identified in Aim 1.

For each job, a job task description, weights and frequency of parts handled whether or not job rotations take place, etc. was obtained from written job descriptions, observation and video recordings of employees, and interviews with these employees and/or their supervisors, and direct measurement (e.g., measurements of workstations and weighing of tools and parts handled).

A task analysis was performed for each of the jobs. The job was described according to several major tasks (or work elements). Employees were asked to evaluate the task descriptions and changes were made accordingly. Next, employees were asked to simulate each of the tasks performed on the job and to then rate the level of muscular exertion experienced on a Borg CR-10 scale (Borg 1990) associated with each of the elemental tasks for the left and right forearm, left and right upper arm, left and right legs, upper back, and lower back. The CR-10 scale can be treated as a semi public unit for different kinds of inter-individual comparisons. Grant, Habes and Putz-Anderson (1994) applied the CR-10 scale to subjectively assess the perceived intensity using the 10 of the scale to represent the heaviest effort perceived by the participant (effort perceived during MVC). For tasks involving complicated motions, requiring co-contraction by a large number of muscle groups they found RPE to be a good predictor of grip force with a correlation coefficient of 0.63. Using the CR-10 ratings as a proxy for %MVC, a high linear relationship (R=0.77) was found between rated perceived exertion and exertion levels by Chin, Bishu and Hallbeck (1995). The ratings of exertion in this study were then categorized into three levels (low, medium and high) of muscular exertion. The muscular exertion data were used in the estimation of required rest allowance, a proxy measure of muscular fatigue (see below).

Video recordings were then made repeatedly within and across days on multiple individuals in two production jobs. The sampling approach involved a random selection of workers, stratified at three different times throughout the day (early, middle and late shift). When a worker could not be found (absent from work or away on break), the observer moved onto the next worker. Therefore data collection was not exactly balanced within and across days. For job studied, 10-15 work cycles were video recorded for each of 3 operators on 1 to 3 occasions per day spread across the shift on 4 to 5 different days covering a period of 8 weeks.

One-hundred eight videos were taken and copied into a personal computer using video editing software. A computerized video analysis package that synchronizes video data with ergonomics assessment methods ($MVTA^{TM}$, NexGen Ergonomics, Inc.) was used to determine the following for each video clip:

1. Mean cycle time (as a crude proxy for repetitiveness)
2. Proportion of time spent in trunk flexion equal to or exceeding 20 degrees
3. Estimated required rest allowance for the low back (100% working time)
4. Estimated required rest allowance for the right shoulder

5. Estimated required rest allowance for the left shoulder

For the MVTA analysis of each video clip, the different task components and posture categories were represented as events coded. The video recording could be played in slow-motion or at full speed with the software. The video player was synchronized with a clock and time line provided in the software. The beginning and end of each task component within a cycle was recorded. All the cycles in each clip were thus time coded. The time for which an individual was in ≥ 20 degrees trunk flexion was also coded with the software. A report function in the MVTA software generated a detailed time study of each video clip. (Figure 1).

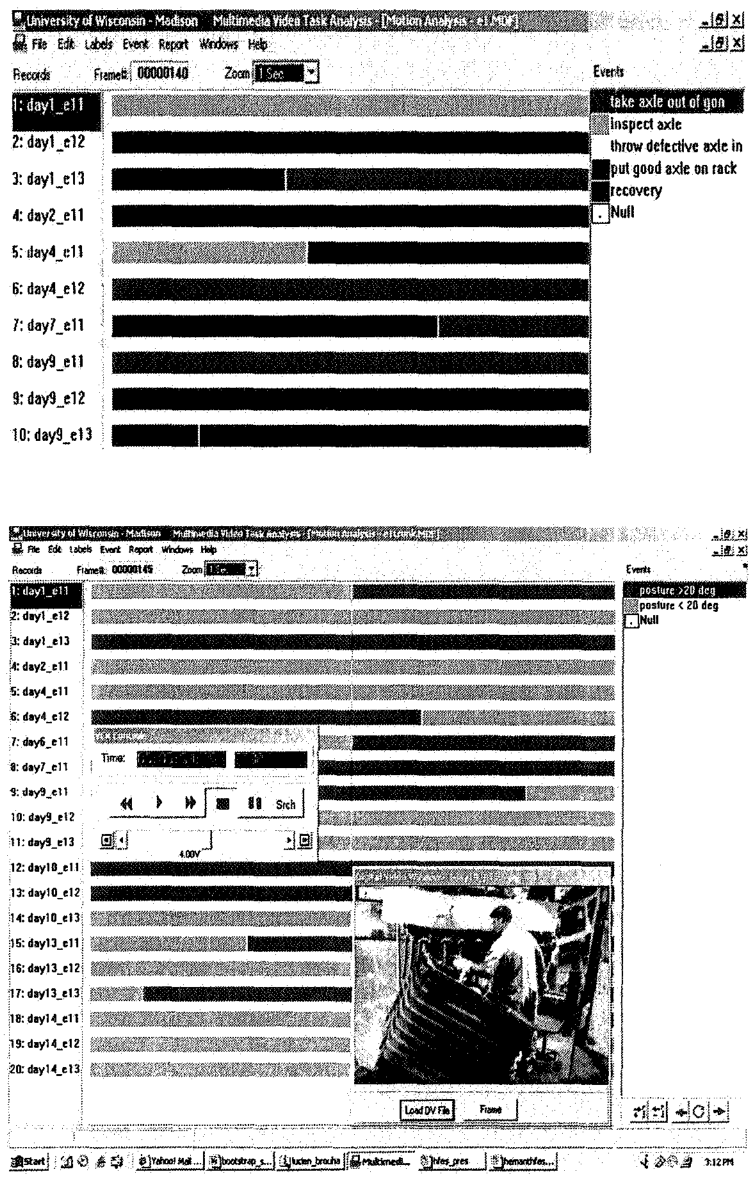

Figure 1. Example MVTA analyses. Different rows represent exposure profiles for different worker-day combinations (video clips). Above different shades of the horizontal bars illustrate how tasks change with time. Below, different shades of the bars illustrate how trunk posture categories change with time. The video and recording control features of the software are also shown.

The variables were chosen because they were thought to be poorly correlated and may have different sources of exposure variability. Since the rest allowance rates are derived from psychophysical ratings of muscular exertion and trunk flexion may be influenced by body size, work methods and other characteristics of the individual, these variables were hypothesized to have fairly large inter-individual variability. Since the jobs are fairly repetitive, the variability in cycle time across individuals is thought to be much lower. The correlation of the five variables was evaluated.

The estimation of the required rest allowance for the low back and shoulder was based on a method developed by Rodgers (1997). This job analysis technique considers localized muscle effort intensity, duration, and frequency to predict fatigue accumulation during work. The basis for the method is derived from static muscle fatigue data from studies performed by Rohmert in the early 1970s (Romhert, 1973). By estimating the length of time and intensity (approximately 30% MVC or less for "light" efforts, 50% MVC for moderate efforts, and 80% MVC for heavy efforts) of efforts for different muscle groups, the cycle time necessary for recovery can be estimated. If the actual cycle time is less than the required cycle time, then there is an associated accumulation of fatigue. Rodgers (1997) suggests that most workers for about an hour of continuous work may sustain job tasks associated with less than one-minute of estimated fatigue accumulation for every five minutes of work. The rest allowance can be calculated using the formula:

$$RA = 18 (t/T) e^{1.4} * [(f/F)-0.15] e^{0.5} * 100\% \qquad \text{Eq. 1}$$

Where:
RA = rest allowance as a percent of working time
t= time of static effort (seconds)
T= total time of work cycle (seconds)
f/F=proportion of the maximum muscular exertion associated with the effort

This method was applied to the exposure data to estimate fatigue accumulation rate associated with each of the video clips. The distribution and duration of tasks performed within cycles, along with psychophysical ratings of muscular exertion were used in the equation above to estimate the fatigue accumulation rate. Rest allowance as defined above was modified so that it estimates the rest required per minute of work (a rate, rather than a percentage of working time).

The variables required for the calculation of the rest allowances included duration and intensity of muscular exertion with the assumption of static exertions of short durations. The muscular effort associated with each task component for individual worker was derived from the Borg CR 10 ratings for individual task-body part combination by each worker. These ratings serve as a proxy for the percentage of maximum voluntary contraction (% MVC). The time variable for individual cycle was obtained from duration times corresponding to the task components from the time study report of the MVTA.

The values were substituted in the fatigue accumulation model to calculate the net predicted rest allowance for individual task element in each cycle. Any rest time within the cycle was deducted from the net predicted recovery time to calculate the adjusted recovery time for individual cycle. The rest allowances for individual cycles were summed across all cycles recorded in an observational period. This cumulative rest allowance for a clip served as a proxy for the accumulated fatigue from attributed to the job. All the required calculations were performed in Microsoft Excel.

Data analysis included an evaluation of the overall distribution of each of the variables within each of the occupations, a correlation analysis of the variables to ensure that the correlation of those select for further study was low, and an evaluation of the components of exposure variability across workers and days. The exposure variability involved using analysis of variance (ANOVA) to investigate the contributions of the variables to the overall exposure variability. In order to estimate the contribution of exposure variability across workers, across days and within day, a two way analysis of variance (ANOVA) with repeated measures was performed. A hierarchic classification described by Burdorf, Verburgh and Elders (1994) in which a number of workers are sampled from a population randomly across different days with repeated measurements within each shift was used. An unbalanced nested model where the repeated measurements within a shift are nested within the levels of days which in turn are nested within the worker was used for the ANOVA procedure. In this model the three factors, workers, days and shift were treated as random effects variables. The model partitioned the total variance into between worker and within worker components. The within worker component consisted of the across days and within shift subcomponents. The PROC VARCOMP procedure with the MIVQUE0 method for estimation of sum of squares was implemented in SAS to calculate the components of variance, since this technique estimates the variance components in a general linear model with random effects as encountered in this data set (SAS/STAT User's guide, 1999).

Specific Aim 3, "Determine whether or not the evaluation methods are predictive of musculoskeletal endpoints"

During the assessment of both the Millwrights and the self-paced manufacturing work, muscular discomfort data were collected daily for the workers observed. However, no clear trends between the daily exposure information and the daily muscular discomfort data were found and therefore the results are not included in this report. It is thought that the lack of findings could be due to the poor sensitivity of the self-reported symptoms and/or a lack of statistical power since relatively few employees (8 Millwrights, 9 manufacturing) were studied.

Specific aim 4 Test and evaluate the different exposure assessment strategies (e.g., number of workers and measurement periods) to determine which offers the most reliable measurement of exposures", and

The data collected with PATH and the video-based job assessment method was used to determine the number and length of exposure assessment periods required for a reliable estimate of exposure. It is essential to examine the sufficiency of the sample size to understand if the estimate of mean exposure from the sample reflects the average exposure of the job. An empirical approach based upon sampling with replacement (i.e., bootstrapping) can be applied to estimate the optimal sample size to obtain a reliable estimate of exposures (Burdorf and van Riel, 1996, Hoozemans et al, 2001). Bootstrapping is a statistical approach that allows inferences to be made without strong assumptions about a sample's population distribution. Instead, the major assumption in bootstrapping is that the distribution of a sample approximates that of the population of interest (i.e., that the sample is unbiased). The distributional properties of the population parameter are estimated by sampling the original study population repeatedly with replacement. Bootstrapping first requires the construction of an empirical probability distribution from a sample by placing a probability of $1/N$ (where N is the number of measurements in the sample) at each of the original sample's points. A sample (or set) of size n (where n is a number $\leq N$) is then drawn with replacement from the empirical probability distribution. The statistic of interest is calculated from the sets of 'resamples'. The resampling of the empirical probability distribution and statistical calculation is then repeated many times. A probability distribution of the statistic is then constructed from the resamples by placing a probability of $1/x$ (where x is the number of resamples) at each point. This probability distribution is the bootstrapped estimate of the population's distribution for the statistic. To construct confidence intervals around the statistic of interest, at least 1,000 resamples are recommended (see Mooney and Duval, 1993 for a detailed description of bootstrapping). A more detailed description of the statistical approach is offered by Hoozemans et al. (2001).

Since ANOVA demonstrated that many exposures in Millwrights varied similarly to construction work that have been published previously (Paquet, 2001), this report covers new results to inform strategies of video-based assessment for self-paced manufacturing work. Five scenarios were chosen for testing sampling strategies. (Table 1).

Table 1. Different sampling strategies tested for the video-based ergonomic job analysis of self-paced manufacturing jobs.

Strategy No.	Strategy Description	Sample Size (# of video clips)
111	One worker observed once on 1 day	1
113	One worker observed 3 times within a day	3
131	Three workers were observed once on 1 day	3
311	Three workers were observed once on 3 different days	3
353	Three workers were observed 3 times within a day on 5 different days.	45

Visual Basic macros were written in MS Excel to simulate each of the exposure assessment strategies. For each simulation, 2000 resamples of the appropriate sampling scenario were taken with replacement. The precision of the empirical estimate was defined by a 95% confidence interval around the mean exposure estimate (Hoozemans et al, 2001), with a smaller confidence interval indicating higher reliability.

Specific aim 5, " Pilot test the job analysis methods and strategies".

A third job was selected to determine if the general guidelines for exposure assessment developed from the first two self-paced manufacturing jobs could be applied to a different self-paced manufacturing job. For this, 45 videos were recorded repeatedly during and across days on 2 operators. The same MVTA analysis for exposure variables, and the same statistical analysis procedures were applied to the new data set. Originally a pre- and post- intervention ergonomic interventional analysis was planned for this occupational group, but the plant's Ergonomics Committee was unable to implement an ergonomics intervention for this occupation during the study period.

Results

Specific Aim 1. Evaluate the MSD experience of the workforce retrospectively from 1994-2001 to identify departments and jobs that require special attention.

The analysis of incidence rates demonstrated that the facility experienced higher rates of injury and illness than the comparable industrial averages in the U.S. The types of injuries recorded most frequently at the facility included strains and sprains, suggesting that many of the injuries were perhaps related to problems with ergonomics (i.e., overexertion). The second-most frequently reported injury type in the plant was lacerations and punctuations, having rates that were approximately 1.5 times higher than the comparable industrial average. The third most common injury in the plant was fracture, with incidence rates approximately double than the industrial average. The body parts that were most commonly affected were the trunk and upper extremities. The incidence rate for injuries of the trunk and for the upper extremities was approximately 4 times the industrial average. Many of the jobs in the forging plant required excessive physical effort or highly repetitive tasks, but the characterization of the risk factors for jobs prior to this study had been poor. (Table 2)

There were a total of 2056 reported injuries at the forge facility reported between October 1999 and August 2001. A vast majority (94.8%) did not result in days away from work, leaving 106 injuries that contributed to 1591 total days away from work. The most frequently reported injury type was "struck by foreign object" (25% of the cases) but these types of injuries accounted for less than 1% of the days away from work. Strains were the second-most frequently reported injury type and accounted for a majority of the total days away from work (54%). (Table 3)

The highest frequency of injuries was found for the skilled maintenance (e.g., Millwrights), back end presses, die room departments, contributing to about 40% of the total days away from work. Skilled maintenance had the highest number of days away from work due to injury, followed by the back end press and die room departments. (Table 4)

Table 2. Selected incidence rate calculations (annual rates per 10,000 full-time workers) for the plant.

Injuries	Rate within the Plant	Rate for Metal Forging and Stampings (OSHA, 2001)
All	4110	1560
Sprains or strains involving days away from work	703.0	122.2
Fractures	37.4	19.3
Laceration or puncture	59.8	51.6
By body area:		
Trunk	493.6	115.6
Upper extremities	426.3	102.1
Lower extremities	246.8	49.0

Table 3. Injury frequency and resulting days of away from work by type of injury for the plant.

Injuries	Number of Injuries	Resulting Days away from Work
All	1725	1510
Struck by Foreign Object	514	5
Strains	421	819
Laceration	367	56
Contusion	291	128
Sprain	41	42
Crushing	17	82
Inflammation	16	3
Fracture	7	227
Hernia	6	74
Amputation	1	42
Infection	1	32
Other	43	0

Table 4. Injury frequency for cases and total days of away from work by department.

Department	Number of Injuries	Resulting Days away from Work
Maintenance – Skilled*	325	385
Back End Presses*	270	154
Die Room*	206	178
Front End Presses	203	1
Warm Forming	172	30
Relay Rod Upsetting*	150	95
Inspection	127	74
Hotforming	87	159
Maintenance – Non-skilled	87	73
Material	65	38
6 inch Upsetting	56	17
Extruding	51	37
Shears	48	105
300 & 700 Ton Presses	47	78
General Stores	20	11
Cleaners	19	22
Cold Header	13	0

* Department selected for further study (aims 2-5)

Millwrights (skilled special trades) and occupations in the departments of back end presses, die room and relay rod upsetting were selected for further study (aims 2-5) due to the high frequency of injuries and days away from work.

Specific Aim 2. Develop reliable and precise ergonomic job analysis methods for skilled trades jobs (non-cyclical skilled labor) as well as production line jobs for the effective evaluation of interventions in manufacturing plants

Millwrights

The analysis of the exposure variables for the Millwrights trade suggested the following:

1. Observational work-sampling methods are appropriate for estimating the proportion of time individuals are exposed to ergonomic risk factors for different Millwrights tasks due to high exposure variability
2. Exposures to awkward body postures are high and are particularly variable.
3. Exposures to manual material handling was observed rarely and were therefore less variable, at least for the individuals and tasks observed in this study.

Before formal data collection, tests of inter-observer reliability showed that the proportion of observations in which observers were in agreement exceeded 0.8 for all exposure variables, and was 0.95 for the coding of task (Table 5). These results are fairly consistent with previous studies, and attempts were made to improve inter-observer reliability through subsequent discussions about the reasons for exposure misclassification and about clarification of the definitions of exposure categories.

Table 5. Inter-observer reliability of computerized-PATH coding for tasks and postural ergonomic exposures (2 coders, 108 observations).

	I. Posture and Task Variables			
Day	**Trunk**	**Arm**	**Leg**	**Task***
Day 1	*0.74*	*0.74*	*0.92*	-
Day 2	*0.90*	*0.83*	*0.98*	*0.93*
Day 3	*0.78*	*0.84*	*0.84*	*0.96*
Overall	**0.81**	**0.810**	**0.90**	**0.95**

*note: Task not coded on day 1 (n=76).

A total of 8,284 observations were made on 8 workers over eight days spanning a period of several weeks. Workers spent 94% of the time on three tasks (Figure 2). Preparation work included fairly nonphysical work (e.g., paper work) related to or in preparation for the task, and therefore no ergonomic problems were found for task. Maintenance included any maintenance necessary to assure normal operation of machine, which included making the necessary adjustments or quick repairs to machines. Fabrication involved the construction of a new product (i.e. creating a part from scratch or carpentry work.). During the observation period, new offices were being constructed in the front of the building, and a new machine was constructed. The Millwrights workers also made machine parts for existing machinery.

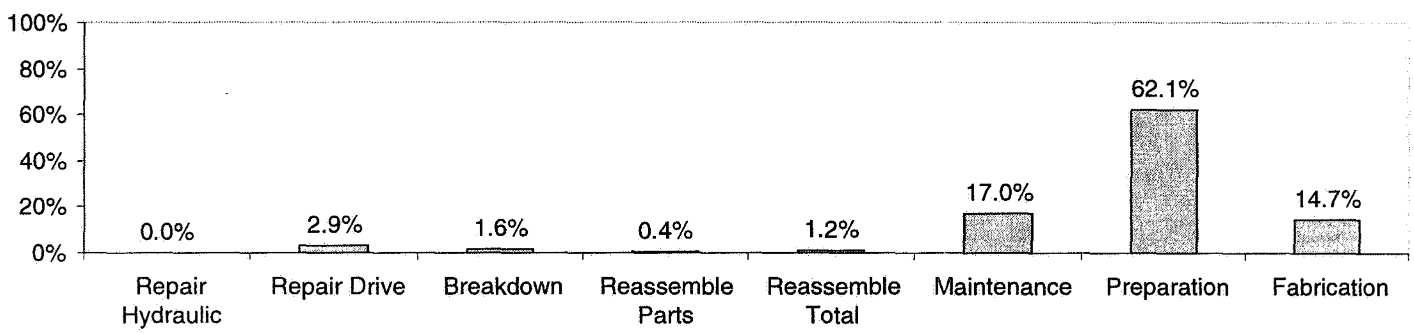

Figure 2. Percentage of total observations for each task (n=8284 on 8 workers taken on 8 days across several weeks).

Exposures. There was a relatively high frequency of awkward trunk and arm postures observed during work tasks, but awkward leg postures and manual materials handling work were not observed very often. Millwrights were required to work in trunk flexion about 45% of the time and had to work with at least one arm above should height about 7% of the time. Squatting and kneeling postures were relatively infrequently (6% and 2% of the time, respectively). Millwrights performed manual materials handling tasks very rarely (<3% of the time).

The ergonomics exposures varied greatly across individuals, tasks and locations in the plant. For example, exposure to trunk flexion of at least 20 degrees varied as much as 3 times between individuals. For some tasks, ergonomic exposures were not present while in others the ergonomic exposures were observed as much as 40% of the time. Exposures to awkward body postures were observed more frequently and were more variable than exposures to manual materials handling. (Figures 3-8).

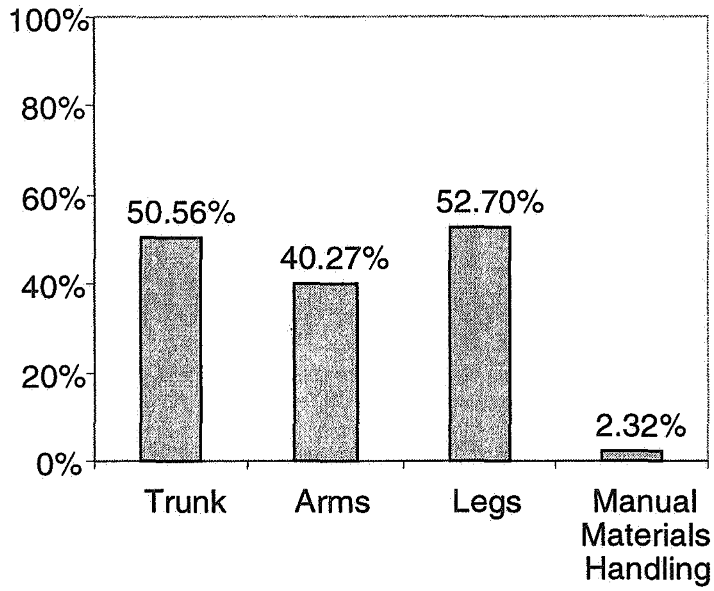

Figure 3. Percentage of observations for which non-neutral body postures and manual materials handling task were recorded (n=8284 on 8 workers taken on 8 days across several weeks).

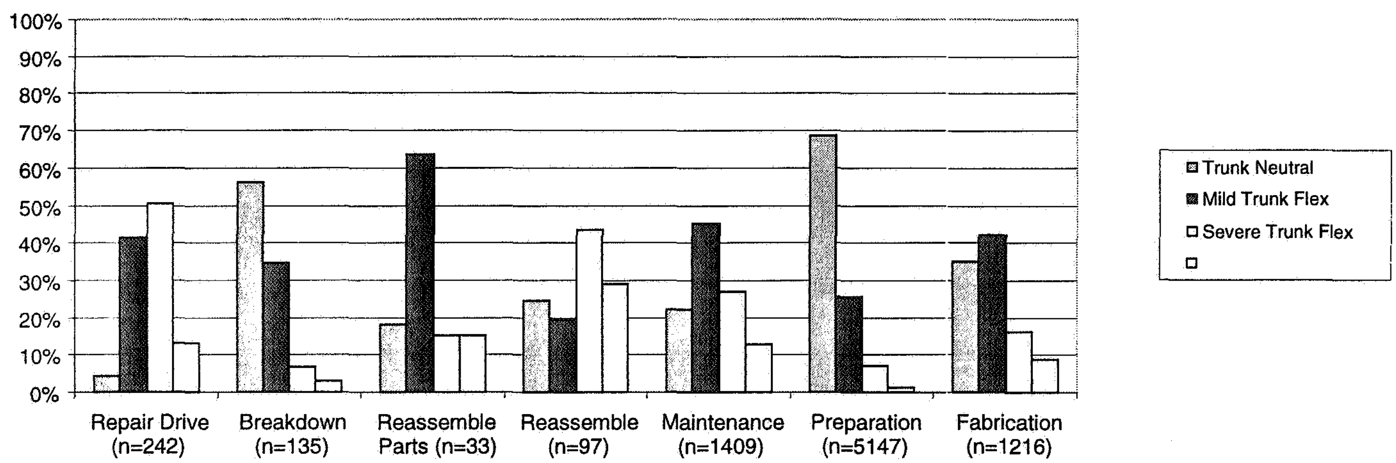

Figure 4. Percentage of observations for different categories of trunk posture differed across tasks.

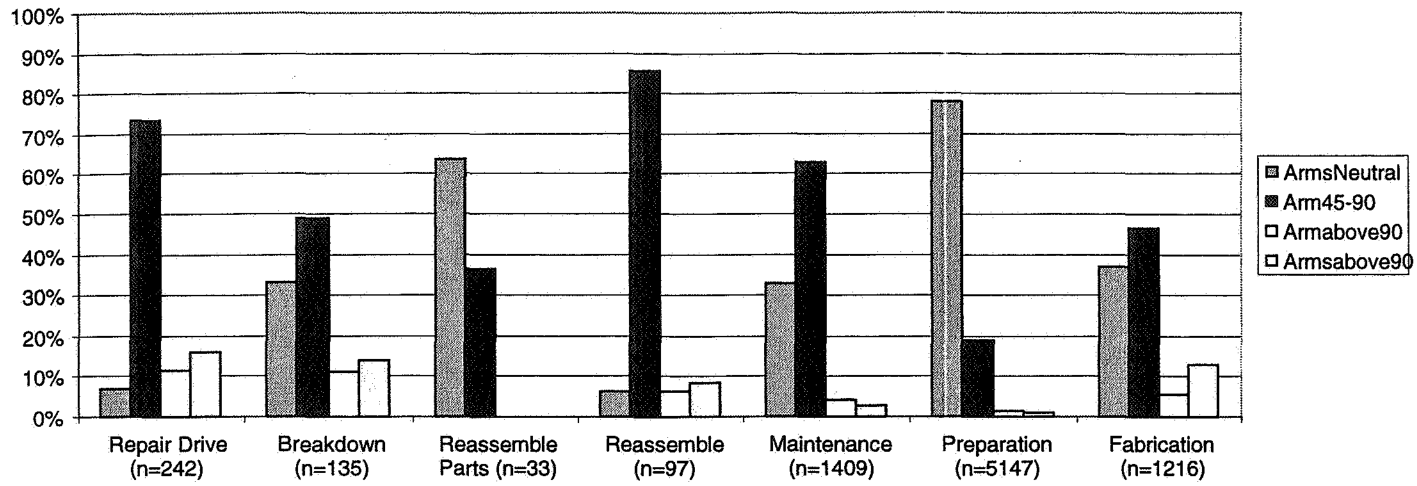

Figure 5. Percentage of observations for different categories of arm posture differed across tasks.

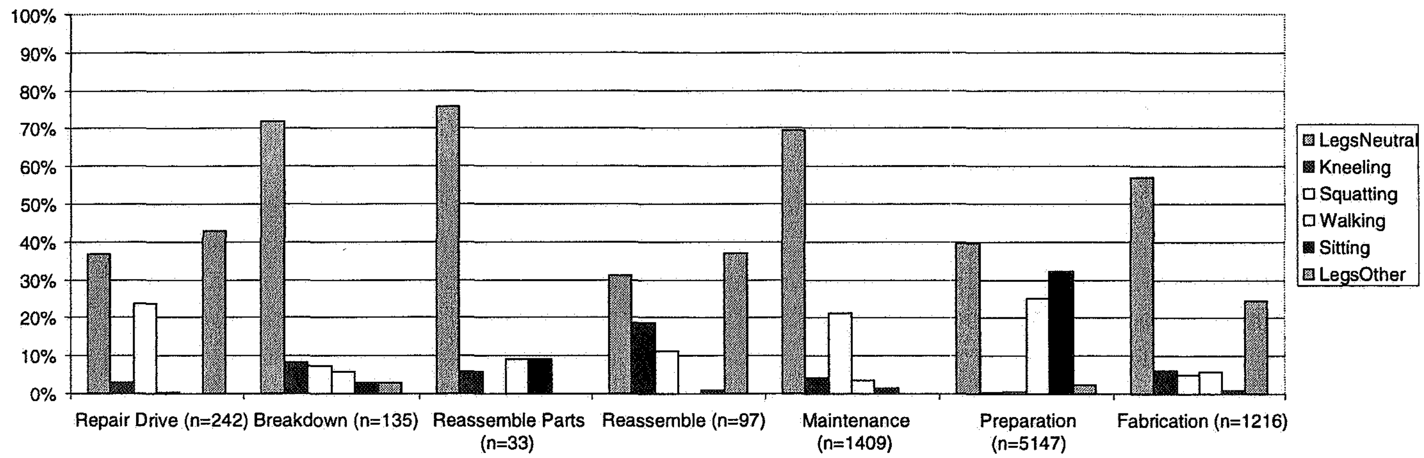

Figure 6. Percentage of observations for different categories of leg posture differed across tasks.

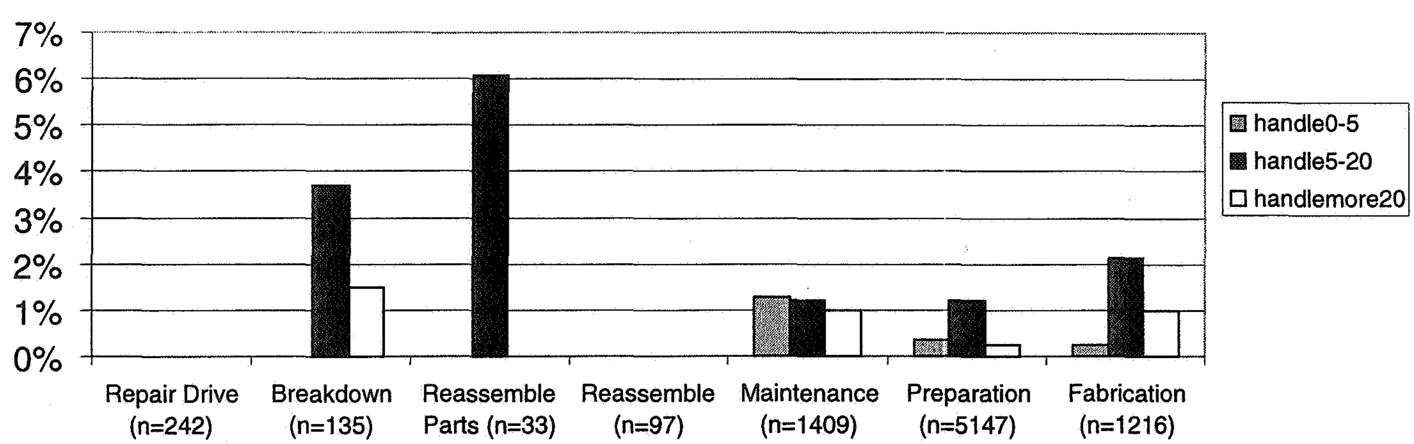

Figure 7. Percentage of observations for different categories of load handling differed across tasks, but were generally low.

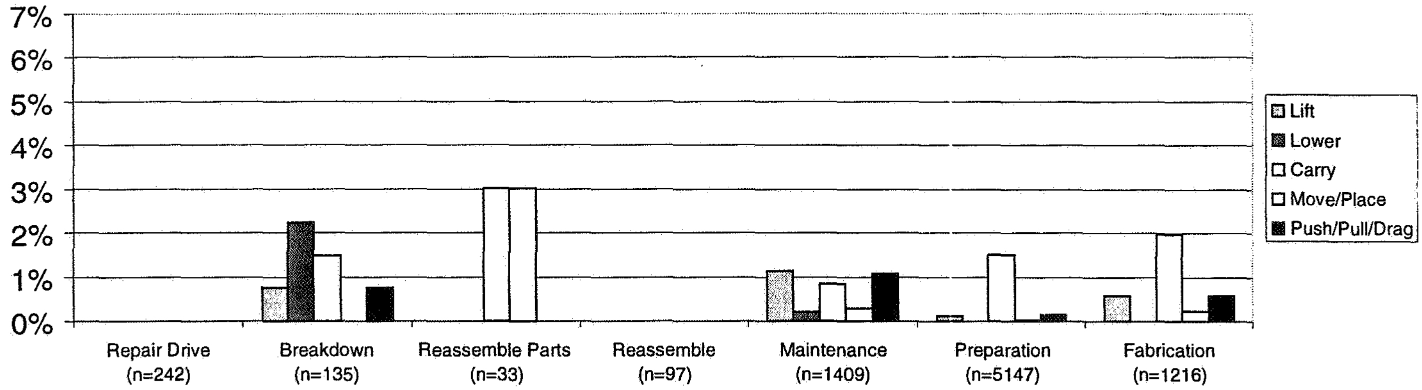

Figure 8. Percentage of observations for different categories of manual material handling activities differed across tasks, but were generally low.

Cyclical Self-paced Manufacturing Jobs

The descriptive analysis of the exposure variables for the axle extruders and relay rod upsetting operators suggested the following:

1. There is a large amount of exposure variability even for cyclic self-paced production jobs. (at least for the variables evaluated in this study)
2. The components of exposure variability and the amount of variability differ greatly across exposure variables and between jobs. Some trends can be identified within job (e.g., Day contributing more to exposure variability to relay rod upsetting, and operator contributing more to required rest allowance variability in the axle inspection and loading).
3. Cycle time is not significantly correlated with the other exposure variables.
4. The required rest allowance estimates for different body parts are moderately to strongly correlated. This is expected as the different variables are derived from the same task distributions of each individual in each video clip.

The results for each are presented below separately for each occupation.

Axle inspection and loading. For this job, operators lifted axles from a bin and inspected parts for defects using a hand-held gauge. If the axle passed the inspection then the axle was loaded onto a conveyor which carried the axle to the extruder. The operation was managed in by a team of three people in a shift. One person manages each operation throughout a shift. (Figure 9)

The mean cycle time of the job was 9.5 seconds with a standard deviation of 3.16 seconds. The mean proportion of cycle time spent with trunk flexed greater than 20 deg was 23.6% for this job with a standard deviation of 10.32 %. The ratio of the standard deviation to the mean rest allowance varied from a minimum of 0.93 for the lower back to a maximum of 1.31 for the right forearm. (Table 6)

Differences in exposures across operators were examined. The range for the mean cycle times for individual operators was 1.2 seconds. Standard deviation as a percentage of mean for cycle time varied from 20% to 41% for individual operators. For mean trunk flexion and low back rest allowance, the standard deviation varied from 31% to 49% and 59% to 85% of the mean respectively. The within operator variability range for the 2 exposure variables is higher than that for within operator cycle time. (Table 7)

High correlations were found between the rest allowance for the lower back and right shoulder and left shoulder muscle groups (r = 0.97 and r = 0.94, respectively). A high correlation (r = 0.97) was also found between the rest allowance for the right and left shoulder muscle groups. (Table 8)

In the variance analysis of trunk flexion, the within day variability was found to be the largest contributor of exposure variance accounting for 77% of total variability. This was followed by day-to-day variability (23%). For the lower back rest allowance, 51% of variability could be attributed to operators, with 37% within day and 12% across days. (Table 9)

Figure 9. Axle inspection and loading operator lifts an axle from a bin.

Table 6. Selected descriptive statistics for exposure variables in axle inspection and loading.

Variable	Mean	S.D.	Range
Cycle time (seconds)	9.5	3.16	4.8-20.7
Trunk flexion (% of observed time)	23.6	10.33	7.8-48.3
Low back rest allowance (seconds/minute of work)	30.7	28.55	0-129.4
Right shoulder rest allowance(seconds/minute)	26.4	30.83	0-129.4
Left shoulder rest allowance(seconds/minute)	30.3	30.97	0-129.4
Right forearm rest allowance(seconds/minute)	21.1	27.77	0-113.9
Left forearm rest allowance(seconds/minute)	25.2	28.05	0-113.9

Table 7. Descriptive statistics for measured variables by operator (axle inspection and loading).

Variable	Operator 1		Operator 2		Operator 3	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Cycle time (seconds)	8.9	1.8	9.6	3.2	10.1	4.1
Trunk flexion (% of time)	21.7	6.8	22.2	9.7	26.7	13.0
Low back rest allowance (seconds/minute)	15.0	12.8	19.2	13.4	54.9	32.4
Right shoulder rest allowance (seconds/minute)	3.6	5.9	17.0	12.3	55.7	32.3
Left shoulder rest allowance(seconds/minute)	3.6	5.9	30.1	17.8	55.7	32.3
Right forearm rest (seconds/minute)	0	0	12.1	10.3	48.2	28.5
Left forearm rest (seconds/minute)	0	0	26.3	16.8	48.3	28.5

Table 8. Correlations between measured variables (axle inspection and loading).

Exposure Variables	Right shoulder rest allowance	Left shoulder rest allowance	Low back rest allowance	Cycle time	Trunk flexion
Right shoulder rest allowance	1	0.98	0.97	-0.32	0.26
Left shoulder rest allowance		1	0.94	-0.36	0.25
Left shoulder rest allowance		1	0.94	-0.36	0.25
Low back rest allowance			1	-0.43	0.28
Cycle time				1	-0.20
Trunk flexion					1

Table 9. Variance contributions of operator, day (nested within operator), and video clip (nested within day) (axle inspection and loading).

Variable	Operator	Day(operator)	Clip (day)
Cycle time (sec)	0	2.7	7.7
Trunk Flexion (% observed time)	0.26	24.4	82.9
Low back rest allowance (seconds/minute of work)	494.3	114	370.5
Right shoulder rest allowance(seconds/minute of work)	796.4	105.9	309.1
Left shoulder rest allowance(seconds/minute of work)	736.6	97.6	366.5
Right forearm rest allowance(seconds/minute of work)	687.9	78.8	229.6
Left forearm rest allowance(seconds/minute of work)	634.6	71.2	288.8

Relay rod upsetting. For this job, the operators were required to heat rods taken from a pallet with an electrical heater. The operators then held the rod in different positions in the die to achieve the multi stage upsetting so that it would form the desired shape. The cycle of the job was the same, though rods of different sizes were formed.

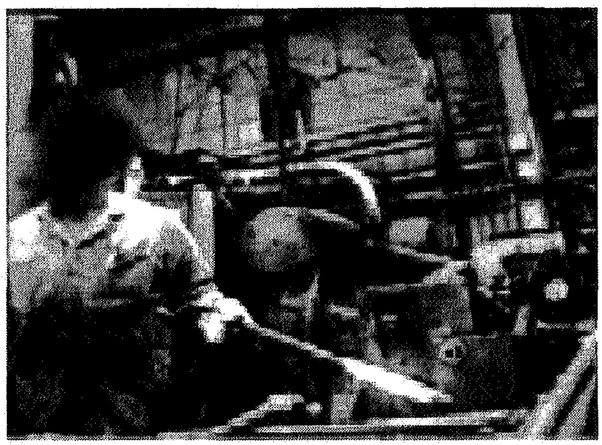

Figure 10. Relay rod upsetting operator removing relay rod from bin heater.

Fifty three video recordings were made across 14 days on 3 different operators. The mean cycle time for the job was 18.4 seconds, with a standard deviation of 4 seconds approximately 22% of the cycle time. The mean proportion of cycle time spent with trunk flexed greater then 20 deg was 24.8%. The standard deviation for the trunk flexion variable was 15%, around 60% of the mean. The ratio of the standard deviation to the mean for the predicted rest allowances for different body parts based on psychophysical ratings varied from a minimum of 0.46 for the lower back to a maximum of 2.33 for the right forearm. (Table 10)

Comparisons made across operators showed that the means of the cycle times varied from a minimum of a 16.9 seconds to a maximum of 20.3 seconds. Within operator variability of cycle times indicated by standard deviation as a percentage of the mean varied from a minimum of 14.2 % to a maximum of 25.6% for individual operators. The relative within operators variability reflected by the standard deviation was high, varying from a minimum of 27% to a maximum of 82 % when measured as a proportion of the mean exposure to trunk flexion. The within operator variability for rest allowances expressed as the ratio of the standard deviation to the mean varied the minimum of 0 to a maximum of 1.71 for the right shoulder and the right forearm. (Table 11)

A high positive correlation was found between the lower back rest allowance and left shoulder rest allowance (R= 0.87) and left forearm rest allowance (R= 0.98). High positive correlation also existed between the left shoulder rest allowance and the left forearm rest allowance. (Table 12)

A variance component analysis was performed to quantify the contributions of operators, across days and within day components. Variability across days accounted for 48% of total variance for the cycle time followed by within day component at 44%. The variability across operators, days and within day accounted for approximately 36%, 38% and 26% respectively. Approximately 51% of total variability in lower back rest allowance could be attributed to day to day changes. (Table 13)

Table 10. Descriptive statistics for measured variables (relay rod upsetting operators).

Variable	Mean	Standard deviation	Range
Cycle time (seconds)	18.4	4.05	13.8-35.0
Trunk Flexion (% observed time)	24.8	15.10	0-53.6
Low back rest allowance (seconds/minute of work)	15.7	7.31	0.09-29.8
Right shoulder rest allowance(seconds/minute of work)	1.3	2.35	0-10.5
Left shoulder rest allowance(seconds/minute of work)	13.0	4.85	0-23.4
Right forearm rest allowance(seconds/minute of work)	0.47	1.10	0-5.5
Left forearm rest allowance(seconds/minute of work)	14.1	5.92	0-25.5

Table 11. Descriptive statistics for measured variables by operator (relay rod upsetting).

Variable	Operator 1		Operator 2		Operator 3	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Cycle time (seconds)	18.3	3.7	20.3	5.2	16.9	2.4
Trunk flexion (% of observed time)	15.3	12.6	36.4	10.0	22.5	14.7
Low back rest allowance (seconds/minute of work)	21.7	7.5	17.0	5.5	9.7	2.3
Right shoulder rest allowance(seconds/minute of work)	0.57	0.98	3.6	2.9	0	0
Left shoulder rest allowance(seconds/minute of work)	13.9	5.2	15.5	5.0	10.1	2.4
Right forearm rest allowance(seconds/minute of work)	0.7	1.2	0.8	1.4	0	0
Left forearm rest allowance(seconds/minute of work)	18.1	6.5	15.5	5.0	9.7	2.3

Table 12. Correlations between measured variables (relay rod upsetting).

	Right shoulder rest allowance	Left shoulder rest allowance	Low back rest allowance	Right forearm rest allowance	Left forearm rest allowance	Cycle time	Trunk flexion
Right shoulder rest allowance	1	0.66	0.47	0.76	0.49	0.085	0.38
Left shoulder rest allowance		1	0.87	0.57	0.93	-0.13	0.31
Low back rest allowance			1	0.59	0.98	-0.11	0.08
Right forearm rest allowance				1	0.56	-0.13	0.16
Left forearm rest allowance					1	-0.13	0.13
Cycle time						1	0.15
Trunk flexion							1

Table 13. Variance contribution attributed to operator, day (nested within operator), and video clip (nested within day) for relay rod upsetting operation.

Variable	Operator	Day (Operator)	Clip (day)
Cycle time (seconds)	1.3	9.6	6.3
Trunk flexion (% of observed time)	83.6	87.5	86.8
Low back rest allowance (seconds/minute of work)	35.8	15.4	14.3
Right shoulder rest allowance(seconds/minute of work)	3.5	0.6	2.4
Left shoulder rest allowance(seconds/minute of work)	7	8.4	10.5
Right forearm rest allowance(seconds/minute of work)	0.1	0	0.9
Left forearm rest allowance(seconds/minute of work)	17.7	11.9	11.44

Specific Aim 4. Test different exposure assessment strategies (e.g., number of workers and measurement periods) to determine which offers the most reliable measurement of exposures

Axle inspection and loading. The pattern in the confidence intervals of the different exposure assessment strategies was found to be consistent across the 3 variables tested. The confidence interval was lowest for the strategy where the average of 3 observations over 5 different days on 3 different operators (353) was used to estimate mean exposure. For the case where 1 observation (111) was taken at random from the sample, the confidence interval was largest. When the sample size was 3, the confidence interval was smaller than that for the sample size of 1, but larger than the sample size of 45. The size of the confidence interval around the mean for a sample size of 3 differed with the sampling approach adopted. The confidence interval was smallest for the strategy where the 3 samples were distributed across days and operators at different times within day (311). It was largest when 3 samples were taken on the same day for a single person (113). A 26% reduction in the confidence interval was observed when the 3 samples were taken across operators on different days (311) compared to taking the observations on the 3 different days on the same person (131) for the lower back rest allowance estimates. (Figures 11-13).

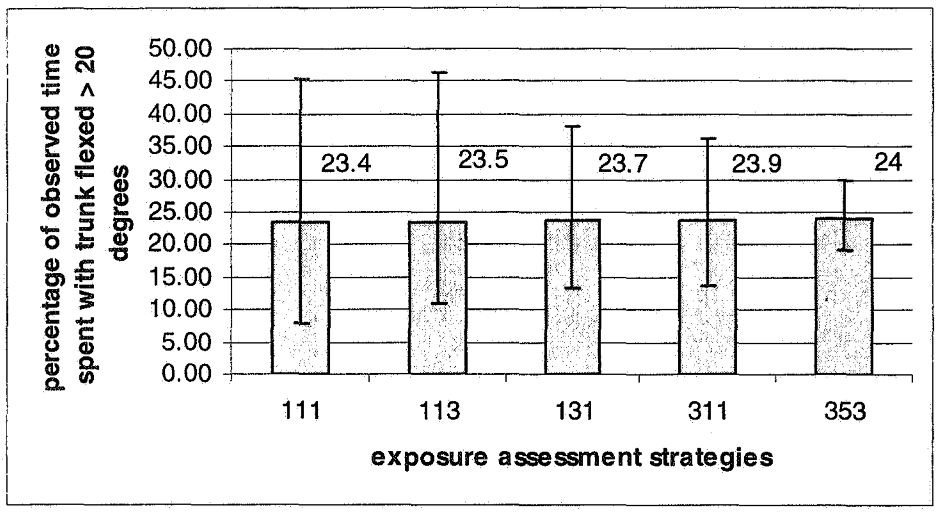

Figure 11. 95% confidence intervals of 5 strategies for estimating mean percent observed time spent in trunk flexion for the axle inspection and loading.

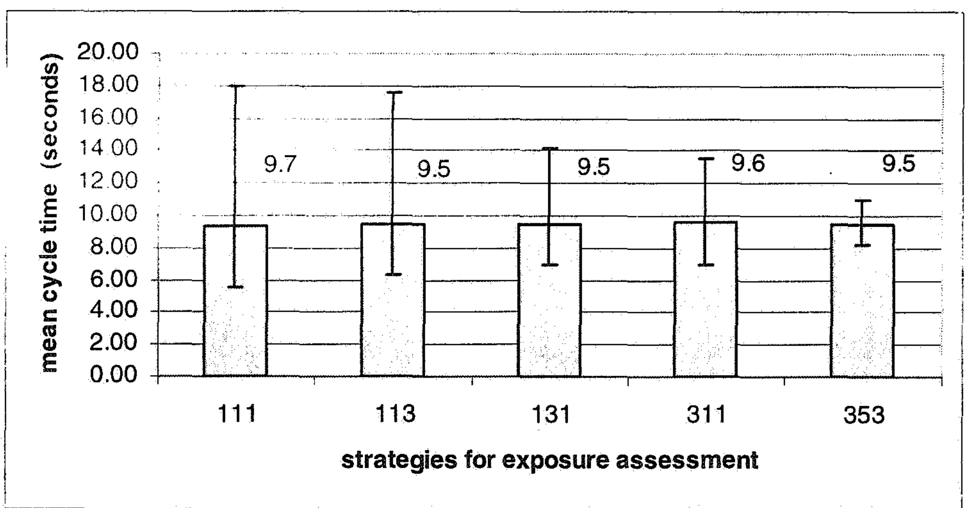

Figure 12. 95% confidence intervals of 5 strategies to estimate mean cycle time for the axle inspection and loading.

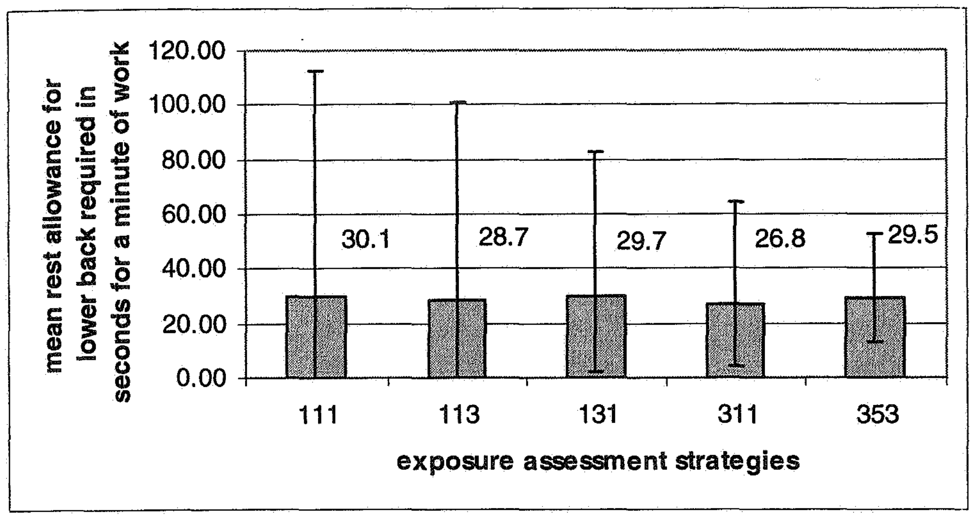

Figure 13. 95% confidence intervals of 5 strategies to estimate the mean lower back rest allowance for the axle inspection and loading.

Relay rod upsetting. Similar trends were found for the relay rod upsetting job. For the estimate of the mean cycle time, the strategy with 3 samples on a day for the same operator (113) had the highest confidence interval and the strategy with the mean of 45 samples (353) had the lowest confidence interval. The strategy with 1 sample (111) had a larger confidence interval than the strategy with the mean of 3 observations on the same person on different days (131).

For the estimates of mean time spent in trunk flexion and mean rest allowance for the lower back, the results for the 5 exposure assessment strategies were similar. The strategy with 3 observations on 5 different days across 3 different operators had the lowest confidence interval. The strategy with 1 sample had the highest Among the 3 strategies with 3 samples each. The strategy with 3 observations on a single day on a single operator had the highest confidence interval. The strategy with 3 observations across operators and days had the lowest confidence interval .

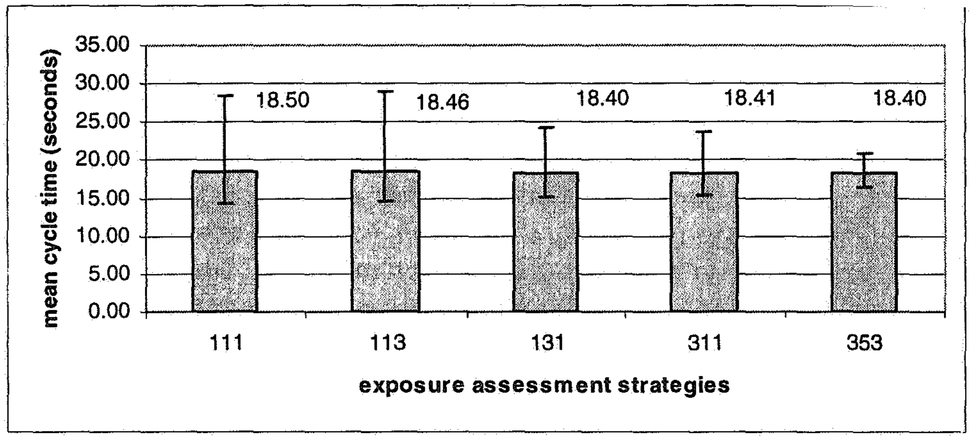

Figure 14. 95% confidence intervals of 5 strategies to estimate mean cycle time for relay rod upsetting.

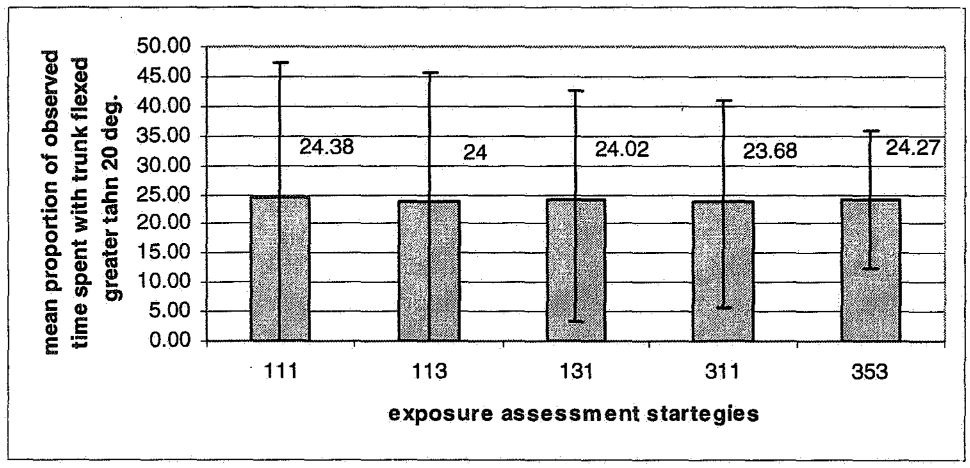

Figure 15. 95% confidence intervals of 5 strategies for estimating mean percent observed time spent in trunk flexion for the relay rod upsetting.

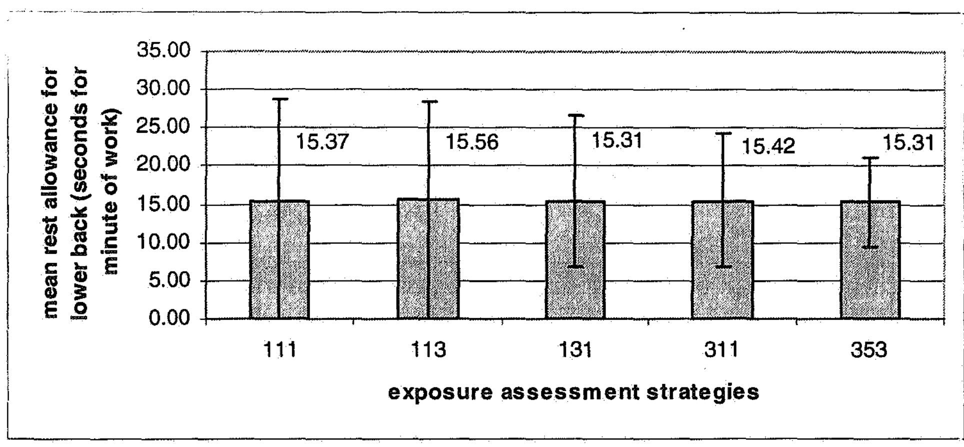

Figure 16. 95% confidence intervals of 5 strategies to estimate the mean lower back rest allowance for the relay rod upsetting.

Specific Aim 5. Pilot test the job analysis methods and strategies

Net shape gear forging. For this occupation, the operator was required to lift the hot billet that arrived via a conveyor by means of a tong and position it in a die. The press was operated by a foot pedal once the billet was in place. After the gear was formed, it was ejected from the die by means of a pneumatic jet placed below the gear in the bottom portion of the die. The press was operated by a 2-member team in a shift. Operators rotated in half hour shifts for the production operations. The rotation schedule required the operators to perform sampling quality inspections and drive forklift trucks when they were not operating the press.

Figure 17. Net shape gear operator lifting materials.

There was no variability in the exposure to mild trunk flexion for net shape gear operation. One of the operators failed to report the psychophysical ratings of muscular exertion needed for the calculation of the required rest allowances. The final data set for this job consisted of 45 data points from 2 operators. The coefficient of variation for the rest allowances varied from a minimum of 1.3 for the left shoulder to a maximum of 2.6 for the right forearm. For the mean cycle time, the standard deviation was approximately 11% of the mean. (Table 14).

Table 14. Selected descriptive statistics for measured variables (net shape gear forging).

Variable	Mean	Standard deviation	Range
Cycle time(seconds)	4.31	0.48	2.54
Lower back rest allowance (seconds/minute of work)	15.14	19.87	57.79
Right shoulder rest allowance (seconds/minute of work)	17.99	23.30	70.59
Left shoulder rest allowance (seconds/minute of work)	28.14	34.82	104.79
Right forearm rest allowance (seconds/minute of work)	17.99	46.77	70.59
Left forearm rest allowance (seconds/minute of work)	24.63	36.60	91.13

Differences in exposures were observed across operators. The maximum coefficient of variation for the cycle time was 0.12 for operator 1. Variability in the rest allowances for the different body parts for operator 1 as indicated by the coefficient of variation was ranged from a minimum of 0.37 to a maximum of 0.51. There was no exposure variability across predicted rest allowances for operator 2. (Table 15)

Between-operator variability composed a minimum of 78.98% of the total variability for the lower back rest allowance and a maximum of 85.21% for the left shoulder. For the cycle times, the within day variability was the largest component accounting for 48.33% of total variance. Between days variability consistently exceeded the within day variability. Between day variability exceeded the within day variability by a 2.1 for the lower back rest allowance which was the smallest and the maximum was 2.7 for the left shoulder. (Table 16).

Table 15. Selected descriptive statistics for measured variables by operator (net shape gear forging).

Variable	Operator 1		Operator 2	
	Mean	Standard deviation	Mean	Standard deviation
II. Cycle time(seconds)	4.53	0.55	4.11	0.29
Lower back rest allowance (seconds/minute of work)	32.45	16.71	0.00	0.00
Right shoulder rest allowance (seconds/minute of work)	38.56	19.02	0.00	0.00
Left shoulder rest allowance (seconds/minute of work)	60.30	25.12	0.00	0.00
Right forearm rest allowance (seconds/minute of work)	38.56	19.02	0.00	0.00
Left forearm rest allowance (seconds/minute of work)	52.77	22.68	0.00	0.00

Table 16. Variance contribution attributed to operator, day (nested within operator), and video clip (nested within day) for net shape gear forging operation.

Exposure	Operator	Day (Operator)	Clip (Day)
Cycle time (seconds)	0.073	0.055	0.137
Right shoulder rest allowance (seconds/minute of work)	726.4512	126.6936	50.91478
Left shoulder rest allowance (seconds/minute of work)	1787.9	226.7484	83.5936
Right forearm rest allowance (seconds/minute of work)	726.4512	126.6936	50.91478
Left forearm rest allowance (seconds/minute of work)	1368.1	180.4843	72.1634
Lower back rest allowance (seconds/minute of work)	513.60	92.94	43.78

The 95% confidence interval for the estimate of the mean cycle time was the lowest when 3 observations were made on 5 different days on 3 different people (353), and highest when 1 sample (111) was taken. Among the strategies with 3 samples, the strategy with 3 samples distributed across operators and days had the lowest confidence interval (311). (Figure 18)

For the low back rest allowance, the interval for the strategy with 45 samples (353) was the smallest, followed by the strategy with the 3 samples across operator and days (311). (Figure 19)

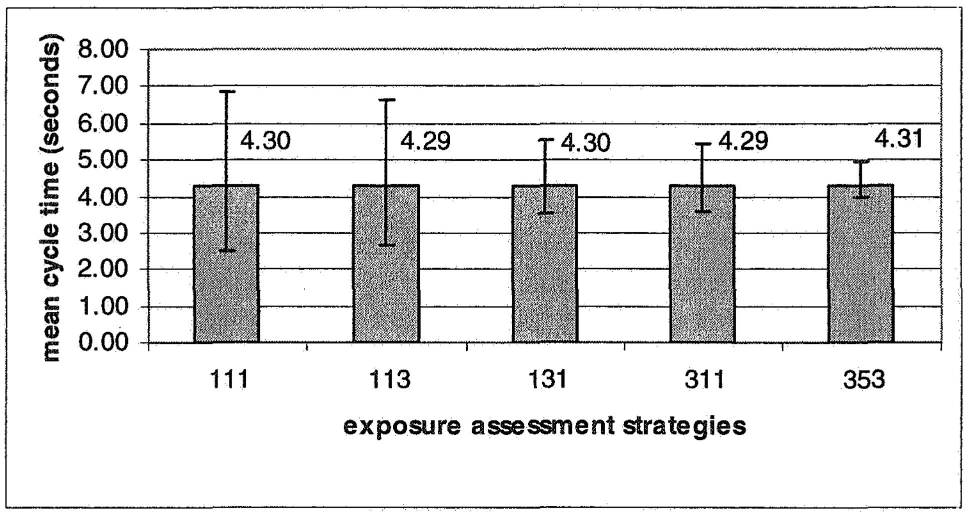

Figure 18. 95% confidence intervals of 5 strategies to estimate mean cycle time for the net shape gear forging.

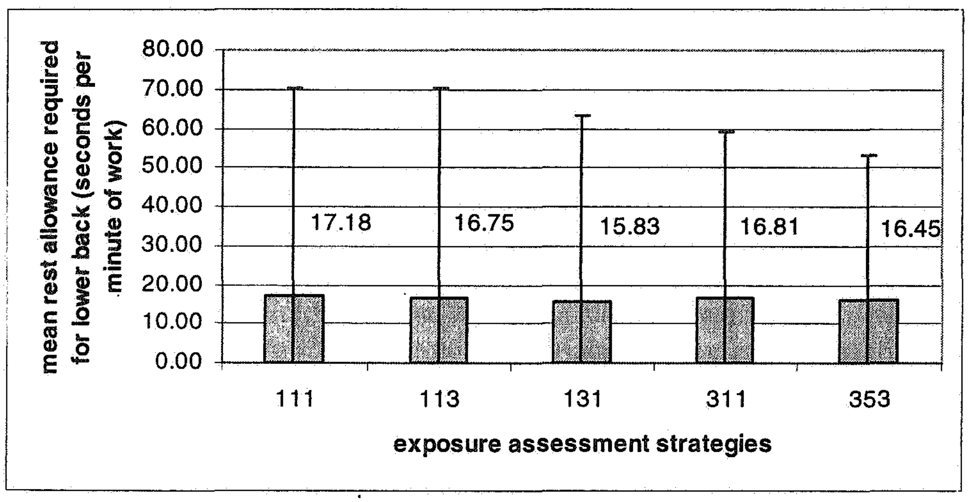

Figure 19. 95% confidence intervals of 5 strategies to estimate mean lower back rest allowance for the for net shape gear forging.

Discussion

The incidence of injuries at this forging facility was extremely high, and the Ergonomics Committee recognized the need for improving its Ergonomics Program and was originally enthusiastic about the development of informative and reliable ergonomic risk factor surveillance tools prioritize jobs in terms of their needs and to evaluate the effects of interventions on exposures. Paquet (PI) and Vena (Co-PI) developed ergonomics exposure methods and strategies to provide more precise estimates of exposure frequently than typically found in checklist-type ergonomic job analysis methods. The relationships between the sampling strategies and measurement reliabilities was also determined for these methods.

However, several original study aims were not fully met in this work. The Ergonomics Committee was unable to use these new methods and strategies to evaluate an ergonómics intervention in the plant primarily for 2 reasons: 1) the Committee failed to put in place during the study period an intervention that was thought to change exposures for multiple workers simultaneously, and 2) the Committee lacked the resources to effectively incorporate the alternative exposure assessment methods into their ergonomics process. Efforts by the researchers to link measured exposures and health outcomes did not provide informative results due to a lack of statistical power and lack of variability across jobs in exposures (i.e., only 4 occupations from 4 departments were studied and those that were selected had a perceived ergonomics problems).

Nevertheless, the study did provide new information that can be used to improve ergonomics exposure surveillance in future studies. Existing practices of ergonomics exposure surveillance such as the use of checklists that require one to rate exposures on an ordinal scale after a short observation period appear to lack the precision and reliability, making it difficult for exposure-response relationships to be found when they exist and masking the true effects of interventions on ergonomics exposures. The results of this study suggest that new ergonomic exposure assessment practices can be used to improve measurement precision and reliability for epidemiologic research and ergonomics practice for the cyclic and non-cyclic manufacturing jobs. Knowledge of the exposure variance components is necessary to design exposure assessment strategies that are reliable. Accounting for possible sources of variance should be an important part of the measurement strategy especially to improve the efficiency of the strategies.

For the Millwrights work, exposures to awkward body postures were high and varied greatly across workers and over time. Although not shown in the results of this report, it would appear that the posture variability profiles of this group are similar those in the conventional construction trades. In order to obtain reliable estimates of the highly variable exposures for groups of workers at least 6 days of measurements on multiple workers may be required. Manual materials handling work for Millwrights was observed rarely and therefore was associated with much less exposure variability. For exposures that do not vary much day to day, reliable estimates of long-term exposure levels for groups of workers may be achieved in 1 or 2 days of assessment.

Perhaps the largest contribution of this study was in the evaluation of exposure variability and developed of video-based ergonomic exposure assessment strategies for cyclic self-paced manufacturing jobs. Most methods for evaluating ergonomic exposures in practice and in research assume that manufacturing work is cyclical, having little variability over time, and therefore exposures over short periods are thought to be indicative of those over long periods. For the self-paced manufacturing work evaluated in this study, ergonomic exposures often varied considerably across workers and during different observation periods. The evaluation exposures across multiple people and during multiple times within and across days is therefore needed for a reliable estimate of many ergonomic exposures. Such practices should be exercised by ergonomics field researchers and ergonomics practitioners in the future.

Conclusions

1. Exposure to awkward postures vary similarly to those found in conventional construction work and may require in Millwrights work extremely long observation periods (e.g., >6 days) for a reliable assessment of exposures for specific construction tasks.
2. Exposures in cyclic self paced production jobs in forging industry also vary significantly over time and people.
3. Effects of the sources of variance are not same across all exposure variables for the same job.
4. The sampling strategy will impact the reliability of exposure estimates for a given sample size.
5. Single video recordings of 10 or fewer cycles are likely not to provide reliable estimates of ergonomic exposures for self-paced manufacturing work
6. Reliability of exposure assessments may be increased by making repeated measurements, particularly when multiple workers are measured across multiple days.

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PUBLICATIONS AND PRESENTATIONS

Journal Articles

Paquet, V, et al.: Video-based Exposure Assessment Strategies for Self Paced Manufacturing Work. (working paper)

Proceedings

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Presentations

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"Exposure assessment strategies for ergonomic risk factors in automotive manufacturing". A poster presented at the State-of-the-Art Research (STAR) Symposium: Perspectives on Musculoskeletal Disorder Causation and Control, Columbus, OH, May 2003.

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