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What is This?

PHYSICAL EXPOSURE ASSESSMENT IN A LARGE PROSPECTIVE UPPER EXTREMITY MUSCULOSKELETAL DISORDERS STUDY

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This paper describes a battery of physical exposure assessment methods used in a large prospective upper extremity musculoskeletal disorders study. Different from some previous prospective studies, this study collects health and physical exposure data for each study subject rather than at a group level. Subjects are recruited from different job categories based on their hand activity exposure categories. Multiple exposure assessment methods are used to measure job physical exposures such as force, repetition, and work posture. This will allow us to compare the sensitivity of different exposure assessment methods in predicting the risk for upper extremity musculoskeletal disorders. Procedures have also been taken to monitor inter-observer reliability for some observational analyses. During the first year of the study, baseline exposure measurements have been collected from 607 volunteers at 11 different worksites. Follow-up measurements have also been collected in these worksites. Whenever a participant has a significant job change, a new exposure assessment is conducted at the new job. This paper will primarily discuss the various exposure assessment methods used in this study, and use some preliminary results to demonstrate some of the data reduction methods.

INTRODUCTION

Musculoskeletal disorders (MSDs) account for a tremendous number of lost workdays and cost to industry in the United States (NIOSH, 1997; GAO, 1997). The Bureau of Labor Statistics (BLS) reported 308,000 cases of illness due to repeated trauma in 1995 which accounted for 60 percent of all work-related recorded illnesses (GAO, 1997). The National Institute for Occupational Safety and Health (NIOSH) reported that about 700,000 (32 percent) of the cases involving lost workdays annually were attributed to repetitive motion disorders or overexertion (NIOSH, 1997). Reducing workplace illnesses and hazards is the first priority of the Washington State Department of Labor and Industries. Many work-related physical risk factors (exposure) have been associated with the development of MSDs (NIOSH, 1997), however, research demonstrating causality between workplace risk factors and MSDs development is needed to more effectively target prevention efforts. A prospective study of work and its relationship to the development of MSDs will provide us with valuable knowledge needed to accomplish this goal.

Recently, NIOSH launched a consortium of prospective 5-year epidemiological studies focusing on upper extremity MSDs, low back disorders and hand-arm vibration related disorders. This paper will present some preliminary work of an upper extremity work-related MSDs study that Washington State is conducting.

Previous epidemiological studies have used group physical exposure measurement method and realized the weakness of that approach (Fallentin, 2001). For example, Fallentin and his co-workers found that despite efforts to optimize group homogeneity by stratifying workers into subgroups focusing on task-related exposures, the within-group variance proved to be larger than the between-group variance for several of the shoulder postural variables (Fallentin, 2001). To overcome this problem, the current study will collect data of both health and physical exposure at the individual level. This paper will only focus on the part of physical exposure assessment.

Different physical exposure assessment methods have been developed during recent years by various researchers. While information on the sensitivity, reliability and usability of the different methods is scarce, the

current study will use several different methods to estimate the same type of the exposure so as to address these issues.

METHODS

The study plans to recruit approximately 1000 volunteers from the manufacturing and service sectors during a 3-year period. An initial cohort of approximately 600 to 700 workers in the first year will be recruited and new workers will be added to the population as participants leave the workplace. Although all workers are eligible, recruiting may be targeted in some jobs to ensure suitable numbers in each job exposure category for statistical power in comparisons. Workers will be classified by job into one of six job exposure categories based on observational assessment (this will be explained in the next paragraph). To reduce possible confounding by a company's work environment, participating companies will be limited to only those with enough volunteers in at least 3 job exposure categories.

The job exposure categories are based on the combination of observed hand force (low and high force) and repetitive hand motions (low, medium and high repetitions). Initially, workers will be classified at the job level into one of the six job exposure categories based on observations made during a preliminary facility walk-through. These walk-through categorizations are done following hand repetition and peak force scales developed by Latko (1997). This is adjusted to the individual level during the physical exposure assessment. The assigned category for a worker in a job is the worst job exposure category, i.e. the highest force and repetition combination, of the various tasks that constitute the job.

The actual physical exposure assessment occurs during a site visit, at which time data are collected through job sampling. Relevant data include: video filming of task performance, significant force measurements, observational measurements and task distribution information. Job exposure is calculated using the task distribution information that is obtained through worker's interview. Job sampling is done at the task level. For a cyclic single-task job, a 15-minute video recording is collected, as well as other measurements for that 15-minute sample. For a cyclic multi-task job, a 10-minute video recording is done for each cyclic task, to a maximum of 4 tasks. If a task has very little variation and its cycle time is short, the recording time is reduced to 5 minutes. For a non-cyclic single-task job, 3 randomly selected 5-minute job samples are collected during the workday. For a non-cyclic multi-task job, 2 randomly selected 5-minute job samples are collected for each

task. Two video cameras are used in the video recording to capture the work performance. The cameras are synchronized using a light signal.

Significant force measurements taken during the site visits include measurements of object weights, push/pull forces, pinch and power handgrip forces. Object weights and push/pull forces are measured using a force gauge, and are also subjectively estimated by an ergonomist using a scale from 1 to 10. Pinch and power handgrip forces are measured using a force match method (Bao, 2000), and estimated by an ergonomist using a scale from 1 to 10. Hand forces are also estimated subjectively by the worker using the Borg scale (Borg, 1982).

The on-site observational measurements include hand activity level (HAL), based on a scale of 0 to 10 and duration of exertion (% of cycle), efforts/min, hand/wrist posture, speed of work and task duration per day that are based on scales from 1 to 5. These observational measurements together with the force measurements will allow us to calculate the hand activity risk level using the ACGIH's HAL TLV (ACGIH, 2001), and the Strain Index (Moore & Garg, 1995). Correlation analysis is conducted to study the relationships between the different observed parameters with the job exposure categories.

All these parameters are collected at the baseline site visits, and may also be collected again at follow-up visits, if a worker has changed jobs and the physical exposure has changed significantly. The follow-ups are conducted every 4 months. The detailed procedures of deciding whether a job re-filming is needed or not starts with a questionnaire. The questionnaire asks whether the worker's job has been changed since last study visit. If the answer is positive, the worker is then visited by one of the ergonomists, who may interview the worker and/or supervisor to understand the changes and observe the job performance to evaluate whether the changes have any significant impact on physical exposure at this job. The ergonomist may also use the previously recorded information at the job to make the judgment.

Videotapes of task performance are digitized and several analyses are performed using the video clips. A task analysis is performed using a time study program (MVTA - Yen &

Radwin, 1995). Frequency and duration of activities involving the observed significant forces are calculated. Using the same program, frequency, duration and duty cycle of hand exertions and frequency of upper arm movements are also calculated. To reduce the possible observer bias during analysis, two observers analyze each videotaped task sample for the hand exertion and upper movement analysis. Between-observer variability will be estimated using kappa analysis. The overall averaged data for the task will be used for further analysis.

The videotaped task performance is also used for two different posture analyses: event-based and time based. The event-based posture analysis is done at the task level. Ergonomists observe the videotaped task performance and complete a postural observation form to indicate the "most common" and the "worst" postures of the different body parts for that task. The data are categorical, i.e. 0° to 15°, 15° to 45°, etc. The time-based posture observation is based on randomly selected still images (ranging from 25-75 frames per task depending on the number of tasks per job, totally 75 to 100 frames per job analyzed). The analysts observe the synchronized images taken by two cameras from two

different angles and estimate the angles of joints by clicking on a picture for the corresponding body part (Figure 1). This will record the corresponding posture data in degrees, i.e. 5°, 14°, etc. All these analyses are performed on a database program developed by us. The data from the time-based posture analysis are later grouped into categories for further data analysis. To reduce observer bias, posture observations of the chosen frames are shared by two analysts. Between observer variability is estimated using kappa analysis. RULA (McAtamney & Corlett, 1993) and REBA (McAtamney & Hignett, 1995) scores can be calculated from the posture observations in the further analyses.

To improve the consistency of the time-based postural observations, two observers, during practice sessions, estimate the postures of 92 postural images. The images are of a volunteer at specific postural angles determined by goniometers. The between-observer agreement (reliability) and the validity for the different body parts are estimated at different precision levels (5°, 10° and 15°) using the kappa analysis. The observers then receive feedback on their observations from an ergonomist and attempt to improve their observational skills based on the results.
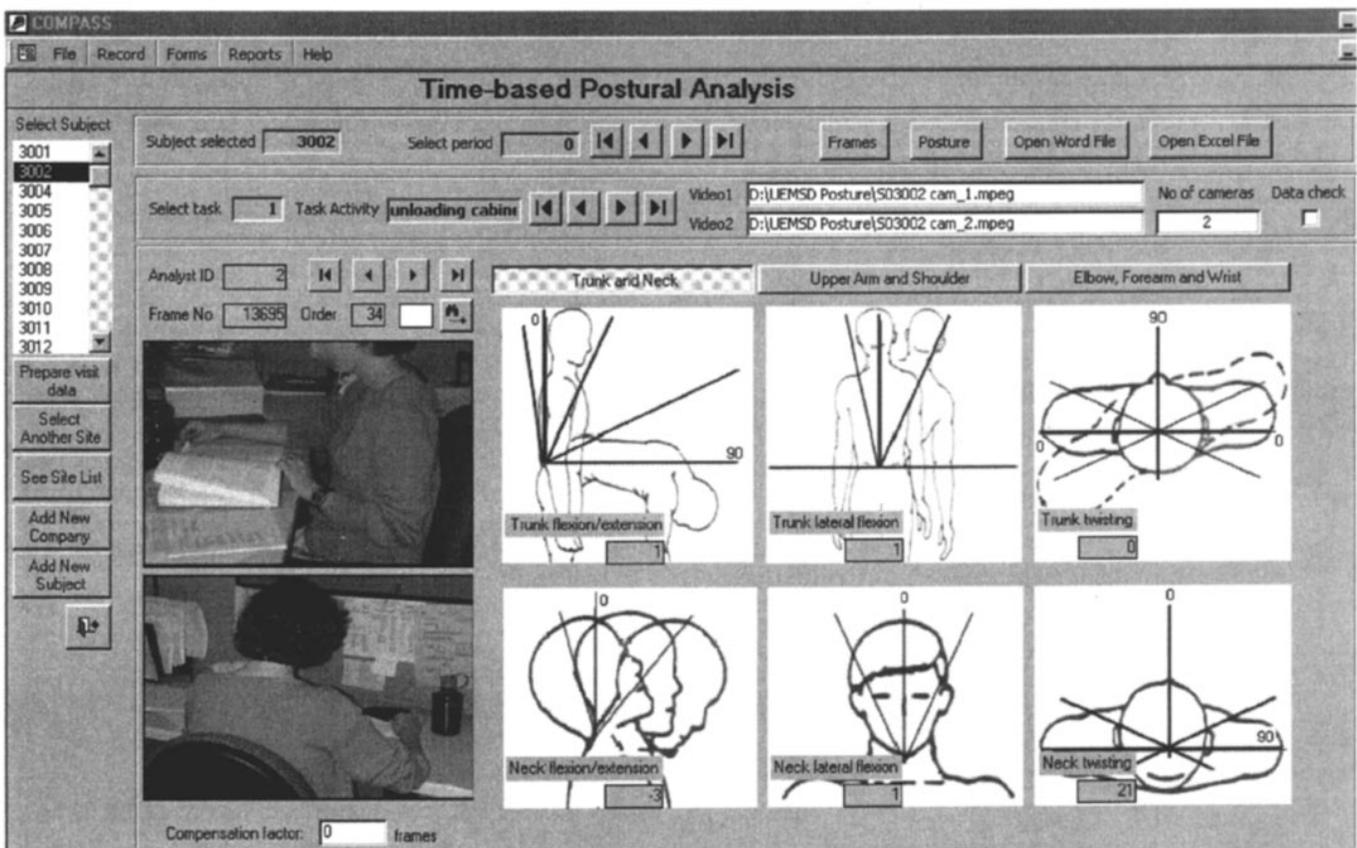

Figure 1. A "click" method is used to estimate the posture angles in the time-based posture analysis (demonstration only, data not represent the actual posture)

RESULTS

Since this study is on-going, only partial sample data are presented, but this will provide insight into the methods used in this study. In the first year of the study, data have been collected from 11 companies. The companies represent a large variety of industries of manufacturing (such as large-scale laundry facility, sawmill and plywood mill, electronic assembly work-places, window and cabinet manufacturers, and radiator and exercise equipment manufacturers) and service (such as hospitals) sectors. A total of 607 baseline and 77 follow-up exposure assessments have been con-ducted. Table 1 shows a distribution of the subjects at baseline measurement by the job exposure categories and companies. Four hundred and twenty-four (70%) jobs are in the low hand force category compared to 183 (30%) jobs in the high hand force category. Most subjects (344 or 57%) are in the medium repetition category, compared to 91 (or 15%) in the high and 172 (or 28%) in the low repetition categories.

servation practice sessions, the inter-observer reliability was good (having moderate to substantial agreement, or kappa = 0.48 to 0.70) for most postures (elbow flexion, trunk flexion/extension, upper arm flexion/extension, upper arm abduction/adduction, and forearm supina-tion/pronation) at a precision level of 5° to 10°. For the upper arm rotation, the kappa statistics was 0.46 (moderate agreement) at a precision level of 15°. Inter-observer reliability was not very satisfactory for obser-vation of wrist postures. For wrist flexion/extension and wrist ulnar/radial deviation observations, the kappa statistics was 0.37 to 0.38 (fair agreement) at a preci-sion level of 15°.

It is time-consuming to do the time-based posture analysis. Only 17% of the analyses have been com-pleted during the first study year. It's relatively easy to conduct the event-based posture analysis, more than 58% of the analyses have been completed so far.

Correlation analysis was conducted between the ini-tial job category (repetition) and some of the on-site observed parameters (HAL, duration of exertion, ef-

Table 1. Subject distribution at baseline in the first study year

Job category	Number of volunteered subjects by worksite											Total by job category
	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	
HF-HR	0	23	3	0	0	12	0	0	0	11	1	50 (8.2%)
HF-LR	0	0	5	0	3	7	0	4	9	7	2	37 (6.1%)
HF-MR	7	13	17	0	18	15	3	3	16	1	3	96 (15.8)
LF-HR	1	1	19	0	2	0	2	2	1	10	3	41 (6.8)
LF-LR	1	1	8	19	23	4	18	20	15	5	21	135 (22.2)
LF-MR	10	11	42	4	25	42	40	33	17	17	7	248 (40.9)
Total	19	49	94	23	71	80	63	62	58	51	37	607 (100.0)
%	3.1	8.1	15.5	3.8	11.7	13.2	10.4	10.2	9.6	8.4	6.1	

Note: H – high, M – medium, L – low, F – force, and R - repetition

Job analyses have been completed for almost 78% of the 684 exposure assessments (baseline and follow-ups). In terms of hand exertion and shoulder movement analysis, More than 24% analyses have been com-pleted. An example of results from one subject is shown in Table 2.

Based on the results of the time-based posture ob-

forts/min, and speed of work). The Pearson correlation coefficients were relatively low (0.27 to 0.42).

DISCUSSIONS

A large loss of subjects has occurred at some of the worksites due to the economic slowdowns. This has

Table 2. Example of result files for the job analysis, hand exertion analysis and shoulder movement analysis (right hand only, estimated weight and forces are based on a 1 to 10 scale.)

SubjectID: XXXXX, Visit period: baseline, TaskID: 1					
Job analysis (for significant forces)	Type of force	Level		Frequency (times/day)	Duration (s/day)
		Measured (lb)	Estimated		
	Lift weight	35	4	59	160
	Pinch grip force	15	6	465	3890
	Push force	55	8	98	1892
Hand exertions	Frequency (times/hour) 654		Duration of exertion (s/hour) 1944		Cycle time (%) 54
Shoulder repetitive movements	Frequency (times/hour) 723				

required us to continuously recruit new subjects, which can be difficult at these companies due to the economic pressures. This may prevent us from getting the expected number of subjects. A couple of new sites are to be added into the study. The participants in this study appear to have varied physical exposures (based on the job exposure categories) allowing enough variations for statistical analyses. Future recruitment may need to be more focused on the job categories of high force/high repetition, high force/low repetition, and low force/high repetition to increase representations of these job exposure categories.

Previous studies have used group exposure assessment methods. The problem associated with this approach is that the within-group variance may be larger than the between-group variance for some of the exposure variables (Fallentin, 2001). Our individual exposure assessment approach should be able to overcome this problem. Based on the experience that we gained during the first year of study, we found that some of the variables (e.g. upper body postures) may vary between subjects within the same type of job and workers may also change jobs during the course of the study. Tracking exposure at the individual level will allow us to calculate the total exposure during the three-year data collection period for each individual worker.

A large number of exposure assessment methods have been used to quantify exposure parameters. Different measurements are used to quantify the same aspect of physical exposure at the job. From this study, we will be able to evaluate the different exposure quantification methods and provide guidelines for the selection of exposure assessment methods. One concern at the beginning of the study is whether we are able to handle the large amount of time-consuming analyses with our limited resources. With continuous improvements of our analysis procedures and good cooperation of the team players, we have been able to handle the analyses quite well.

We are still at the initial stage of this project. More results will be forth-coming in the near future.

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