EXPOSURE ASSESSMENT AND MUSCULOSKELETAL

DISORDER RISK FACTORS IN HOSPITAL LABORATORIES

BY

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ABSTRACT OF A DISSERTATION SUBMITTED TO THE FACULTY OF THE

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ABSTRACT

This dissertation research was carried out to examine exposure to biomechanical risk factors for upper extremity musculoskeletal disorders (UEMSDs) or injuries in hospital laboratories. It consisted of three independent studies which commonly addressed biomechanical exposure to risk factors for MSDs in hospital setting.

In the first study, which was performed as part of a larger exposure assessment study, expert observations of ergonomic risk factors were made to examine the inter-rater reliability (IRR) of a newly revised version of the PATH method (Buchholz et al., 1996). Ten jobs were observed at a hospital where two of four raters simultaneously observed each worker onsite. For most of the risk factors of concern, the IRR of the revised method was shown to be good. As predicted, agreement among observers was higher for the jobs with less rapid hand activity and for the analysts with more ergonomic job analysis experience. The results suggest that the revised method reliably assesses ergonomic exposure in the healthcare industry and can be applied to non-routine jobs in other industries.

The second study was conducted to characterize biomechanical exposure to MSD risk factors in hospital laboratories using a subset of PATH observation data collected for the larger study. An exposure frequency for each risk factor was estimated for each of a number of work shifts. The results showed markedly high exposure to postural strain for the distal UE and moderately high hand activity. Such exposures should be assessed in

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relation to specific tasks and equipment design features in order to inform intervention efforts in the clinical laboratory.

The last study was performed to evaluate the effect of work surface height on muscle activity, posture, and discomfort during laboratory simulated pipetting. The experimental design consisted of one independent variable (work surface height) and thirteen dependent variables. Upper extremity muscle activity, wrist posture, neck flexion and discomfort were affected by the work surface height during simulated pipetting. The work surface height significantly influenced around 70% of the dependent variables. The levels of muscle strain and discomfort were markedly higher at the shoulder but neck flexion levels became lower when the work surface heights were increased. A guide of work surface height was recommended for pipette work based on the findings. Such information can be utilized in ergonomic improvement of laboratory equipment design and layout.

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CHAPTER I. INTRODUCTION

A. OBJECTIVE AND SPECIFIC AIMS

The objective of this study was to examine and assess exposure to biomechanical risk factors for upper extremity musculoskeletal disorders (UEMSDs) or injuries in hospital laboratories.

The specific aims of the study were to:

1. Assess the inter-rater reliability (IRR) of an exposure assessment instrument in hospital work: The IRR of a newly revised PATH (Posture, Activity, Tools, and Handling) method was examined with the following sub-aims for physical risk factors in hospital work.

   - To examine IRRs of PATH observations across a convenience sample of 10 jobs in one hospital

   - To compare IRRs between jobs with different levels of hand activity

   - To compare IRRs between raters with different levels of experience in ergonomic job analysis.

2. Characterize the biomechanical exposure to UEMSD risk factors in hospital laboratories: Using the revised PATH instrument, biomechanical exposure to UEMSD risk factors was characterized in hospital laboratories. The sub-aims were as follows:

- To develop a taxonomy that can provide information on work operations and lab organization in hospital laboratories

- To assess exposure to UE postures with respect to job category, level of hand activity, and type of laboratory in hospital lab work

- To assess exposure to hand activity levels with respect to job category and type of laboratory in hospital lab work.

3. Evaluate the effect of a factor on muscle activity and posture during simulated pipetting: For a pipette task investigated in the hospital laboratories, the effect of work surface height on muscle activity, posture, and discomfort of the UE was evaluated during a laboratory simulated pipette task. The sub-aims were as follows:

- To evaluate whether UE muscle activity is affected by work surface height during lab simulated pipette task

- To evaluate whether wrist and neck posture is affected by work surface height during simulated pipette task

- To evaluate whether discomfort is affected by work surface height during simulated pipette task

- To recommend a guide of work surface height for pipette work

The goal of this study was to provide information which could be used to reduce

and/or prevent exposure to biomechanical risk factors for MSDs in hospital laboratories.

B. BACKGROUND AND SIGNIFICANCE

1. Musculoskeletal disorders in hospital laboratories

An overview

Work-related musculoskeletal disorders (MSDs) or cumulative trauma disorders (CTDs) may be caused or aggravated by repetitive motions, prolonged static activities, awkward postures, and forceful exertions in combination with insufficient recovery time (Armstrong et al., 1982). These disorders include tendinitis, carpal tunnel syndrome (CTS) and de Quervain's disease, and are primarily of the soft tissues of the musculoskeletal and peripheral nervous systems (Armstrong et al., 1982; Punnett et al., 1985; Silverstein et al., 1986).

MSDs have been recognized as a leading cause of worker suffering, productivity loss, and worker's compensation cost in U.S. industries (Putz-Anderson, 1988; Bernard, 1997). MSDs have led occupational injury and illness statistics over several decades. According to the U.S. Bureau of Labor Statistics (BLS, 2002), disorders associated with repeated trauma (RTDs) accounted for 65% of the total nonfatal occupational illness cases in private industry in 2001. In hospitals, the incidence rate of RTDs per 10,000 full-time workers was 24.2, which was higher than the average rate (i.e., 23.8) for private industry in 2001 (see Figure 1).

There are many studies which support the association between MSDs and ergonomic risk factors (Bernard, 1997; Walton, 2000; Buckle and Devereux, 2002; Punnett and Gold, 2003; Punnett and Wegman, 2004). For example, CTS is affected by

wrist flexion, especially in combination with forceful exertion (Armstrong et al., 1982) while de Quervain's disease is associated with both wrist ulnar deviation (Armstrong et al., 1982; Lin and Stubblefield, 2003) and thumb extension (Lin and Stubblefield, 2003) in combination with forceful grasping.

MSDs in hospital laboratories

It is documented that lab personnel are commonly found to be at risk for MSDs such as de Quarvain's disease, CTS, tenosynovitis, rotator cuff tendonitis, thoracic outlet syndrome, wrist ganglions, trigger finger, and back injuries (NIEHS, 2001; CDC, 2002). Laboratory workers (e.g., pipette users or microscope workers) have been identified to be at risk of MSDs by a number of researchers (Bjorksten et al., 1994; Ala et al., 1994; NIOSH, 1996; David and Buckle, 1997; Kreczy et al., 1999).

Bjorksten et al. (1994) evaluated the prevalence of hand and shoulder ailments in laboratory technicians with respect to exposure to pipetting. The authors found that the prevalence of hand ailments among the cohort of 128 female pipette users was twice that of the reference of 25,378 female Swedish state employees. In the cohort, those who reported more than 300 hrs per year of mean annual exposure to pipetting had 5 times the risk of hand ailments compared with those who reported 300 hrs or less. With respect to shoulder ailments, those who reported more than 300 hrs had 2.4 times higher risk than that of the corresponding counter group. It was shown that low back problems were significantly less among the lab female technicians than among the state female employees (p=0.04) and that psychosocial factors were not associated with the development of hand ailment.

David and Buckle (1997) conducted a questionnaire survey of the ergonomic problems in pipette users. This study found that pipette users, compared to the control population (pipette non-users from 6 organizations), reported significantly higher elbow and hand complaints. Almost 90% of study subjects in the longest exposure group (continuously doing pipetting work for more than 60 min) were reported to have hand complaints.

Kreczy et al. (1999) documented that up to 80% of microscope employees working daily over a long duration with a light microscope complain about eye strain, back pain, fibromyalgia, or tension headache.

NIOSH (1996) conducted a survey in which 43 lab workers completed a NIOSH questionnaire. This study reported that 47% of the lab workers met the NIOSH case definition for potential upper extremity (UE) MSDs: the hand was the area most commonly affected (40% of workers), followed by the elbow (19%), shoulder (16%), and neck (14%).

In the above studies, some risk factors were more often reported, indicating that they are more likely associated with MSDs in laboratory workers. Such risk factors include repetitive activities, prolonged static motions, awkward postures, forceful exertions, and work environment factors. The workstation design/physical work condition (e.g., adjustable chair, stool, foot support) and pipette design (e.g., automation and reduction of button resistance) were documented for purposes such as productivity and MSD prevention in general (Ala et al., 1994; Kreczy et al., 1999). However, factors such as the psychosocial environment or vibration were rarely addressed in those studies.

Overall, it is recognized that exposure to ergonomic risk factors in hospital

laboratories for prolonged periods can lead to a variety of disabling injuries and disorders of musculoskeletal tissues and/or peripheral nerves.

2. Exposure assessment methods

Observation methods

Observational methods have often been used to evaluate ergonomic risk factors for MSDs in exposure assessment or ergonomic job analysis studies. These methods can provide real-time information on not only the frequency but also the duration of a worker's activity or task in specific jobs. They are useful to collect quantitative data (e.g., proportion of time spent on a posture) and qualitative data (e.g., task sequences) (Drury, 1995). Exposure assessment studies have been widely conducted using a variety of observational techniques such as work sampling based approaches (e.g., Karhu et al., 1977; Buchholz et al., 1996), time study approaches (Armstrong et al., 1982; Keyserling, 1986); and checklists (Keyserling et al, 1993). These methods have weaknesses such as the inability to collect past exposure, time and labor intensiveness, and low reliability for short cycle work.

Bioinstrumentation

Bioinstrumentation approaches are the most accurate and precise methods to obtain ergonomic exposure information. In exposure assessment, these methods have additional strengths, including availability to provide direct measurements of force and joint posture,

but they have weaknesses such as high cost, invasiveness, calibration, instrument

malfunction, long training, and low generality.

Thus, it is suggested that direct measurement methods be used with other strategies

when they can contribute, via direct measurement approaches, for accuracy and reliability

of the exposure assessment under study.

Workers' self-report

Workers' self-report can be obtained via questionnaire, interview, or diary and can

provide ergonomic information on exposure to risk factors both in the past and at the

current time. These methods also offer a high capacity for studying a large number of

workers at somewhat low cost. However, they have weaknesses such as the possibility of

low response rate and information bias. Also there has been a debate regarding potential

lower accuracy and reliability of these methods.

3. Inter rater reliability of ergonomics observation instruments

Inter-rater reliability (IRR) refers to the extent of agreement in results obtained by

two or more observers when observing the same work situation. IRR is not a measure of

association but a measure of agreement. IRR does not provide information on the

accuracy of the instrument. Unlike intra rater reliability, IRR offers information on

agreement between raters who assess ergonomic exposure. In a reliability study of

ergonomic exposure assessment, IRR has been used to evaluate the performance of an

observation instrument when the instrument is developed or revised.

Percent agreement, kappa, and intra class coefficient (ICC) are often used as measures for IRR evaluation. Percent agreement is generally obtained for ordinal or nominal variables in a contingency table but it does not account for chance agreement (Cohen, 1960). Weighted kappa is used for ordinal variables, unweighted kappa is used for nominal variables, and the kappa coefficient is a measure that accounts for chance agreement (Cohen, 1960; Fleiss and Cohen, 1973). The ICC is used for numerical variables (Fleiss and Cohen, 1973) but it can be an unreliable measure when observational data collected for IRR evaluation are not normally distributed.

Evaluations of IRR for ergonomic risk factors by observation have been conducted by a number of researchers (Johnsson et al., 2004; Stevens Jr. et al., 2004; Burt and Punnett, 1999; van der Beek et al., 1992). The levels of agreement vary, depending on the assessment tool used or the agreement measures: for example, Johnsson et al. (2004) tested the IRR of a direct observation tool, showing that kappa coefficients ranged from 0.16 to 0.77, ICC values ranged from 0.95 to 0.98, and percent agreements were 51% to 93%. Stevens Jr. et al. (2004) evaluated the IRR of the Strain Index in an IRR study where the ICC coefficients ranged from 0.43 to 0.93.

Drury (1995) stated that unreliable measures can not prove a hypothesis because one can not have faith in them to tell how the phenomenon of the hypothesis changes. Since an ergonomics observation instrument with low IRR may limit the reliability of measures, IRR evaluation of the instrument is required when the instrument is newly used for a study by multiple raters. Understanding sources of variability in IRR is useful to interpret the results in an IRR study. Therefore, it is important to evaluate the IRR for

ergonomic risk factors in conjunction with sources of variability when the instrument is used for such an IRR study.

4. Exposure characterization in laboratories

Musculoskeletal health outcomes in lab workers have been reported in epidemiologic studies (Bjorksten et al., 1994; David and Buckle, 1997) although these studies were mainly conducted for a single job such as lab technician.
Job title has frequently been used as a proxy for ergonomic exposure, which is related to the advantage of easily describing exposure characterization. However, there is a disadvantage that the job title can not offer detailed information on ergonomic exposure when it is employed alone.

As modern trends in hospital lab work are towards multi-skilling, ergonomic exposures become greatly varied. The quality of exposure characterization can be improved when multiple aspects (i.e., individual, work, and organization factors) are considered or used together in exposure assessment. Furthermore, an ergonomic job analysis with a lab work taxonomy (hierarchical classification system) can make the process of exposure characterization more effective.

It is recognized that total variability in exposure assessment is a result of variability within and between workers in the same job title and variability between job titles (Kilbom, 1994; Punnett and Wegman, 2004). In order to reduce the non-specificity of job title and to avoid potential misclassification of exposures (Park, 2000), the job title can be

used for exposure characterization with other exposure variables including organization factor in hospital laboratories.

5. Muscle activity and posture in lab tasks

Laboratory tasks are documented in lab health and safety guides. Lab tasks often include procedures or activities such as pipetting, microscopy, safety cabinet work, and VDU work. Forceful exertion, awkward posture, and repetitive motion are common risk factors which have been recognized to affect MSDs in lab job tasks such as pipette use and microscope work.

Fredriksson (1995) assessed the strain that was exerted on the thumb when working with automatic pipettes (length: 29 cm and weight: 104 g). The press of the pipette button to the first mark (transferring the fluid) required a force of 4.2 N and to the second mark (releasing the pipette tip) a force of 14.2 N. Subjects in this study used 4.3 to 8.5 % of their maximum voluntary contraction (MVC) to transfer the fluid and 14.5 to 18.4 %MVC to eject the tip. The author, who analyzed the posture of a lab worker using a video-recording, argued that work with a long pipette always requires lifting one's arm in sitting, and such arm lifting usually happens in the standing position as well. This indicates that the pipette can not be operated without lifting the arm due to the length of the pipette, leading to a strain in the upper limbs as well as the thumb during the pipette task.

NIOSH (1996) conducted an investigation in which an ergonomic evaluation was made for lab technicians. Investigators found that the lab technicians were exposed to

different risk factors such as awkward posture, fixed work height, or no leg room at safety cabinets during pipette tasks. The investigators stated that lab tasks included extending the thumb over the pipette plunger, the use of a forceful pinch posture during tip ejection from a multi-channel pipette, and ulnar deviation of the wrist during pipetting.

Biomechanical assessments of risk factors (workstation design) were conducted in microscope work. Kreczy et al. (1999) proposed an ergonomic microscope workstation which, compared to a conventional workstation, significantly reduced muscle activity in the strained muscle groups for 12 microscopists. The proposed workstation was ergonomically designed and included a microscope table, a microscope stand, and a chair.

Sillanpaa et al. (2003) assessed the effects of microscope work on neck and shoulder muscles for 10 microscope workers at two microscope tables (new ergonomic table vs. normal non-adjustable table). The study showed that the muscle activity was significantly lowered at the new table rather than at the normal table with electromyography (EMG) values ranging from 0.74 %MVC to 16.2 %MVC. The authors stated that the new table was designed based on general guidelines in the literature, allowing the microscope to be used with the head in an upright position, the forearms supported, and with less flexion of the upper arms.

As stated in the several studies above, the levels of muscle activity are reported to be as much as 18.4 %MVC in the lab tasks and the workstation design or work surface height seems to affect the muscle levels. However, there is still a lack of information on how muscle activity or posture is affected by work environment factors (e.g., work surface height or workstation design), and how it interacts with other factors (e.g., posture/ workstation interaction). There is little experimental evidence on how these

factors can influence the muscle activity and postures even though the work surface height/workstation design is one of the work environment factors that have been most frequently addressed in ergonomic intervention studies across industries over three decades (Hagg, 2003; Buckle and Devereux, 2002; Westgaard and Winkel, 1997). In laboratory work, it is necessary to understand work environment risk factors in conjunction with the workstation-tool configuration since the use of tools or equipment is so prevalent. In order to understand the effect of work environment factors on biomechanical or psychophysical exposure, it is important to assess the effect of work surface height on muscle activity and posture for a specific task through an experimental study.

C. ORGANIZATION OF THESIS

This thesis consists of five chapters. Chapter I is an introduction of the dissertation research and contains 'objective and specific aims' and 'background and significance.' Chapters II through IV are three independent studies in which each has sections such as introduction, methods, results, discussion, conclusions and literature cited. Chapter II is devoted to inter-rater reliability assessment of a newly revised PATH method in hospital work. Chapter III addresses characterization of biomechanical exposure to upper extremity musculoskeletal disorder risk factors in hospital laboratories. Chapter IV is devoted to a study on the effect of work surface height on muscle activity and posture during simulated pipetting. Chapter V is a conclusion of the dissertation research and contains a summary and conclusions obtained from the three studies.

Although the three studies have different subjects and methodological approaches, they encompass somewhat common areas. In order words, the scope of each study varies in terms of work personnel, work or organization aspects (Figure 2) but the studies commonly address exposure to biomechanical risk factors for MSDs in hospital setting. Thus this dissertation would provide information to understand ergonomic exposure profiles at different points of aspects in hospital laboratories.

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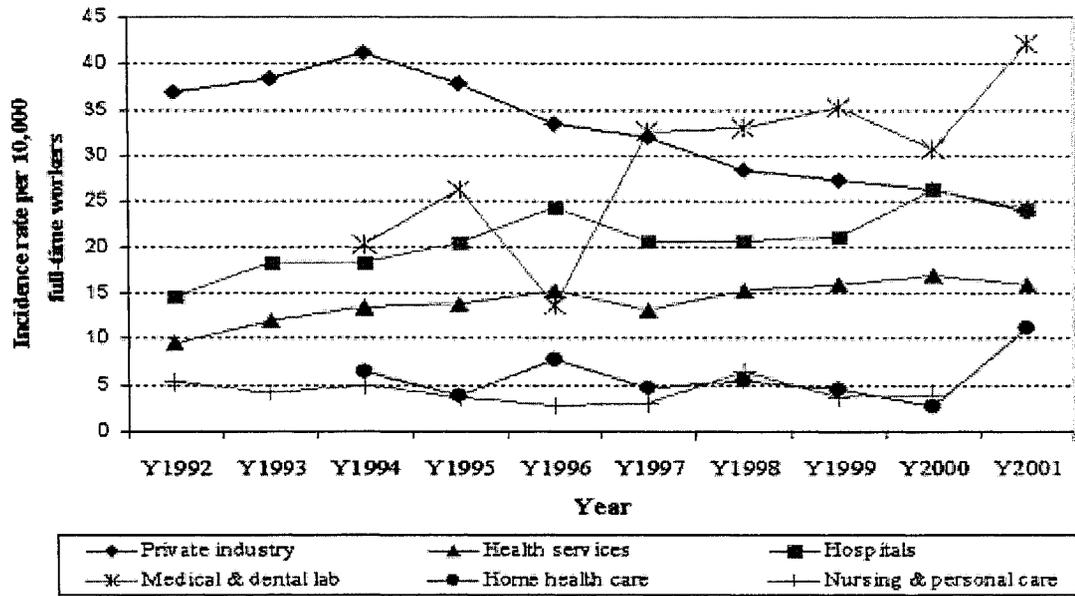
Figure 1. Incidence rate per 10,000 full-time workers for RTDs in US healthcare industry

from 1992 through 2001.
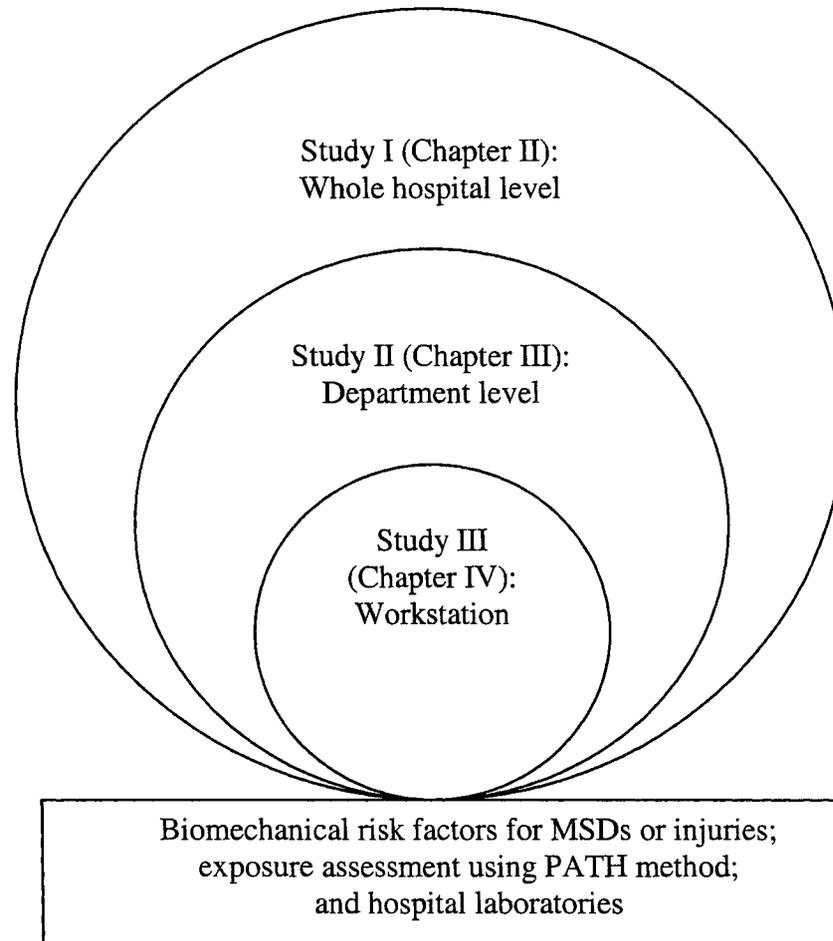
Figure 2. Diagram of three component studies and common areas in this thesis research.

CHAPTER II.

INTER-RATER RELIABILIABITY OF PATH OBSERVATIONS FOR ASSESSMENT OF ERGONOMIC RISK FACTORS IN HOSPITAL WORK

A. INTRODUCTION

Exposure to ergonomic risk factors for prolonged periods can lead to a variety of potentially disabling injuries and disorders of musculoskeletal tissues and peripheral nerves (Bernard, 1997; NRCIM, 2001). Ergonomic risk factors in hospital work have been documented to be associated with work-related musculoskeletal disorders (MSDs) or injuries. The risk factors include repetitive or prolonged motions, awkward postures, forceful manual exertions, and handling of patients and heavy objects (e.g., Punnett, 1987; Park, 1990; Bru et al., 1994; Fuortes et al., 1994; Hignett and Richardson, 1995; Hernandez et al., 1998; Lagerström et al., 1998; Messing et al., 1998; Elford et al., 2000; Camerino et al., 2001; Owen et al., 2002).

Direct observation methods have been used to evaluate ergonomic risk factors for MSDs in many studies (Kilbom, 1994). A variety of observational techniques have been useful for characterizing and evaluating ergonomic exposure to risk factors (e.g., Karhu

et al., 1977; Stetson et al., 1991; Fransson-Hall et al., 1995; Wiktorin et al., 1995; Colombini, 1998). PATH (Posture, Activity, Tools, and Handling) is a direct observation method which has acceptable validity and reliability for physical ergonomic risk factors, including working postures, in construction worksites (Buchholz et al., 1996; Paquet et al., 2001). The PATH method was developed originally for observation of construction workers (Buchholz et al., 1996) although it was envisioned as having potential applications in any type of non-routine work. It has specifically been used to analyse manual materials handling in retail stores (Pan et al., 1999), apple harvesting (Fulmer et al., 2002), and risk factors for hip and knee disorders in dairy farming (Howard, 1997). In the healthcare sector, it has also been utilized to analyse the work of home health care aides (Dybel, 2000) and nursing home employees (Rockefeller, 2002). However, PATH had not been employed in a study of hospital work prior to this study.

A revision of the PATH method has recently been developed to characterize a more comprehensive set of ergonomic exposures across multiple job titles in the healthcare industry. In particular, more details on aspects of upper extremity activity have been added. Both the original and the new PATH checklists have been converted into electronic templates and uploaded into a hand-held computer or personal digital assistant (PDA). In this form, PATH can be used to collect real-time exposure data for more than several hours.

Inter rater reliability (IRR) refers to the extent of agreement in results obtained by two or more analysts when observing the same work situation. Agreement among analysts can be assumed to vary with the specific method used, the exposures being observed, the skill and training of the analysts, and perhaps with characteristics of the job

as well. Evaluations of IRR for ergonomic risk factors have been reported for various exposure assessment methods in various sectors including healthcare (Johnsson et al., 2004; Warming et al., 2004), general industry (Keyserling, 1986; van der Beek et al.,1992; Burt and Punnett, 1999; Pan et al., 1999), and construction (Buchholz et al., 1996 and 2003). However, these studies were conducted mostly for limited sets of job titles and thus did not permit examination of the factors that might influence agreement among analysts.

To evaluate the reliability of the new PATH method and of the observers who were to analyse ergonomic exposure in hospital work, it was necessary to examine the IRR of the instrument. The study was aimed to examine IRRs of PATH observations across a convenience sample of ten jobs in one hospital, to compare IRRs between jobs with different levels of hand activity, and to compare IRRs among raters according to level of experience in ergonomic job analysis.

B. METHODS

1. Study site and subjects

This study was carried out at a hospital in northeastern Massachusetts, USA. It is part of the exposure assessment effort conducted by the PHASE (Promoting Healthy And Safe Employment) project team at the University of Massachusetts Lowell (UML). For training purposes, UML employees were observed. In the final dataset, ten jobs that were observed in the hospital included nuclear medical technician, radiology technician, ultrasound staff, human resources staff, and receptionist. Those participating in this study were 9 female and 3 male workers; their ages ranged from 18 to 62. Each subject agreed to participate voluntarily and signed an informed consent form approved by the Institutional Review Board at UML.

2. Materials

The revised version of the PATH method (Buchholz et al. 1996) was designed to collect multiple ergonomic risk factors of health care workers. It consisted of three templates (ergonomic exposure sampling forms) in which there were 9, 8 and 1 items, respectively; the first 17 items were composed of categories (Table 1 and Appendix A). The first template was very similar to the original PATH checklist and covered physical exposure status such as whole body postures (trunk, leg, shoulder, and elbow), tasks or activities (weight handled, manual materials handling and manual materials handling

action) and other work conditions (noise level and vibration level) at one point in time. The second template was designed to capture hand/forearm risk factors such as neutral/gross grasp, wrist/forearm deviation, pinch grip, keyboarding, contact stress, vibration, weight in hands, and dominant hand, also at a single point in time, at a fixed time interval after the first set of observations. The third step was to determine hand activity level (Latko et al., 1997) after continuous observation of a 15-second work period immediately following the second set. The hand activity level was scored as an integer from 0 to 10.

Paper-and-pencil templates were mostly used for training. After the training period, two hand-held computers or PDAs (Toshiba Pocket PC e310, using the Pocket PC 2002 operating system), were used for PATH observations. InspectWrite™ software (Penfact Inc., USA) was used to create the three electronic templates which were then loaded into each PDA. A desktop personal computer was used as an authoring workstation for transferring and storing exposure data from the PDAs after collection.

Two additional checklists were used in the field to collect a variety of information which might support physical exposure data observed on that day. The "Cover Sheet" was used to record data that might vary from day to day. This included demographic information about the worker(s) observed, the shift, specific tasks observed, work conditions, and work environment factors. The "Super Cover Sheet" focused on relatively constant characteristics of each job title including levels of work routinization: 1) single routine task; 2) multiple routine tasks; 3) single variable task; 4) multiple mixed tasks; 5) multiple variable tasks (Gold et al., 2006; Park, 2000). Operational definitions

were developed for each item of each instrument and were reviewed iteratively during the analysts' training (see below).

3. PATH training of raters

The study used four raters who were research assistants in the PHASE project (Table 2). All raters completed a 30-hour training program for the new version of the PATH method. Raters A, B and C had at least 18 months of experience prior to training but Rater D had no previous experience in ergonomic job analysis. The training program included explanation of the exposure assessment methods and instruments, procedures for data management and cleaning, and practice data collection with feedback on agreement among observers.

As part of the training process, the four raters conducted IRR pilot-tests, analyzing the activities of various workers from video recordings as well as in real time at workplaces in the university. The goal of evaluating agreement was to qualify each rater to collect independent ergonomic exposure data in the hospital. "Training data" were analysed as they were collected and areas of disagreement were explored in order to identify needed revisions in variable definitions or instructions to the analyst. Both during the training period and even to some extent during actual data collection, the PATH templates and variables were iteratively revised as needed to eliminate ambiguity and correct obvious sources of disagreement. PATH modifications were made with reference to literature review and through discussion with a senior researcher who was involved since the beginning of PATH development in the mid-1990's. IRR was

evaluated both before and after the last revisions of the PATH template since these revisions were undertaken precisely to resolve sources of discordance identified by the analysts.

4. PATH data collection

The real-time observations were made on workers who were approached for permission after their supervisors gave consent. Two of the four raters collected exposure data from each worker at the same time and in the same work area. To the extent possible, workers were observed while they performed their typical jobs. Prior to collecting PATH data in each department, an on-site interview and walkthrough were conducted and a brief discussion was held with the worker. The Cover Sheet and Super Cover Sheet were filled out at this time. During job analyses, a stopwatch or electronic timer was used to standardize the time intervals and synchronize the observations of the two observers.

The pair of raters collected exposure data for an observation with 90 seconds in which the 45-30-15 second frame was designed for the three component templates at fixed time intervals: 1) with a vocal cue from a leader, the paired raters simultaneously began to capture exposure and then input data into the first template within 45 seconds; 2) with another vocal cue, two raters captured and input exposure data into the second template within 30 seconds after the first template; 3) with a third vocal cue, the paired raters observed the target worker for 15 seconds and then input data into the third template at the moment of fourth vocal cue. The next observation commenced immediately following another initial vocal cue.

During training, PATH observations were recorded on the paper-and-pencil templates by marking one category for each item. In the hospital, PATH observations were input into the electronic templates of a PDA by touching the screen with the stylus pen. Prior to each day of data collection, the PDA was fully recharged and the clock was checked.

5. Data analysis

Data management.

Field data collected on a PDA were taken back to the university and transferred into the authoring workstation, managed for data cleaning, and stored for future data analyses. The data in the Cover Sheet and Super Cover Sheet were manually entered into a Microsoft Excel spreadsheet and stored in the authoring workstation.

Statistical analysis.

Agreement between each pair of raters was evaluated for each item of all three templates using several metrics: percent agreement, kappa, and weighted kappa. Percent agreement (or proportion of agreement) is defined as the percentage of the total number of agreement in which two raters recorded the same category (Cohen, 1960). However, it does not account for agreement that occurs by chance. Kappa is the proportion of agreement in categorical (nominal and ordinal) variables after chance-expected agreement is removed (Cohen, 1960; Fleiss, 1981), taking the value of 1 when agreement is perfect and 0 when agreement is obtained by chance alone. That is, a positive kappa value means better than chance agreement while a negative value does poorer than

chance agreement. Kappa is undefined when all the data are in one cell of the contingency table (i.e., perfect agreement with no dispersion). Kappa does not make a distinction in the case where some disagreements in assignments are of greater gravity than others, implicitly treating all disagreements as equally serious (Fleiss and Cohen, 1973). Weighted kappa can be used when different kinds of disagreement are to be differentially weighted in the agreement index (Cohen, 1968). Weighted kappa was calculated for ordinal variables with three or more possible categories (Fleiss and Cohen, 1973; Fleiss, 1981). Intraclass correlation coefficient (ICC) is also widely used for measuring reliability of quantitative (interval and ratio) variables (Fleiss and Cohen, 1973). Weighted kappa is identical to ICC under a certain condition (Fleiss and Cohen, 1973).

There are different types of items (i.e., variables) in the three templates: the first template comprises 5 nominal and 4 ordinal variables; the second comprises 7 nominal and 1 ordinal variables; and the third, i.e., hand activity level (HAL), is a continuous variable. The HAL was also categorized according to the original rating system (Latko et al., 1997 and 1999): low= 0 - <3.3, medium= 3.3 - <6.7, high=6.7 - 10.

Percent agreement was calculated for nominal and ordinal variables; kappa was calculated for nominal variables; and weighted kappa calculated for ordinal variables. For each kappa or weighted kappa, a 95% confidence interval (95% CI) was computed. Significance test was made to test the hypothesis that the underlying value of kappa or weighted kappa is zero. Kappa or weighted kappa was not computed for those items where the sample size did not meet the formula $2k^2$ for items ranging between $3 \leq k \leq 10$ categories (Cicchetti, 1981).

Using one-way analysis of variance with random effects model (Shrout and Fleiss, 1979; McGraw and Wong, 1996), the ICC was assessed for each job title and then across job titles within a sub-dataset that was collected by a single pair of raters. The category of 'Not observed or not sure' in each item was treated as a missing value in data analyses. Data analyses were conducted using SAS 9.1 (SAS Institute Inc., 2003).

The HAL scores were also to be analyzed in the continuous form using ICC. However, the data were not normally distributed and thus the ICC analyses were not carried out.

In order to compare IRRs between jobs with different levels of hand activity, the median HAL value was categorized as above (low, medium, or high) for each job. It was hypothesized that IRR would be higher in the lower HAL jobs (i.e., slower hand motions) than in the higher HAL jobs. In the case of observations of multiple workers with the same job title, all HAL data for that job title were combined to compute the median.

For comparing IRRs among analysts, their experience in ergonomics and job analysis was classified into two levels: 1) Level I: professional experience with ergonomic job analysis using a specific method or instrument; 2) Level II: limited experience with short training time. Raters A, B and C were categorized as Level I while Rater D was identified as Level II. Thus Rater pairs AB, AC and BC were all pairs of experienced raters while rater pairs AD, BD, and CD were pairs in which one rater was inexperienced. It was hypothesized that IRRs would be higher in observations made by a rater pair, i.e., with experienced raters in each pair (Group A) than another, i.e., with one inexperienced rater in each pair (Group B).

C. RESULTS

1. Training data

A total of 98 observation pairs were collected through eight IRR training sessions. Twenty six observation pairs collected in the first three training sessions were excluded. Thus, 72 observation pairs were used in calculation of IRRs. The number of observation pairs varied across items because different versions of the PATH templates (i.e., version 5.4, 5.5, and 5.7) were used over the training period. For example, item 4 was revised in version 5.7 so that observations made in earlier versions were not included in the data analysis. Items 17 and 18 were included in version 5.7. Compared to version 5.7, version 5.4 had no categories for each item in the hand/forearm template except weight in hands, and version 5.5 did not have hand activity level. Rater C made the highest number of PATH training observations (41% of the total training dataset), followed by Rater D (25%), Rater A (17%), and Rater B (17%).

The IRR values in the training data were mostly lower than the agreement obtained in the field data collected after the end of the training process (Appendix B). Percent agreement was 80% or higher for 6 out of 18 items. Kappa values were 'excellent' only for hand observed (left or right); 'fair to good' for weight in hands (item #5, for whole body) and keyboarding; and 'poor' for all other variables. The kappa value was undefined for 2 variables, vibration (#9, for whole body) and weight in hands (#16, for hand/forearm). For categorized hand activity level, kappa coefficient was not computed since the sample size requirement was not met.

2. Field data

A total of 443 observation pairs were collected for ten jobs in the hospital (Table 3).

Eight jobs were observed by one pair of raters, and two jobs were observed by two or

three rater pairs. The observation duration for each job ranged from 27 min to 163 min.

Rater B conducted the most PATH field observations (41% of the total field dataset),

followed by Rater D (29%), Rater C (21%), and Rater A (9%). All ten jobs were multiple

mixed tasks (work routinization level = 4), which seems typical of many jobs in the

healthcare setting.

Inter rater reliability

Percent agreement ranged from 42.5% to 100% (Table 4). It was 80% or higher for

12 items. Kappa values were 'excellent' for leg posture, keyboarding, vibration (#15) and

hand observed (right/left); 'fair to good' for trunk posture, shoulder/arm elevation, elbow

posture, weight in hands (#5), neutral/gross grasp, wrist/forearm deviation, pinch grip,

hand/forearm contact stress, weight in hands (#16) and hand activity level; 'poor' for

MMH action, noise level, and vibration (#9). Kappa value was not defined for MMH.

Percent agreements were 80% or higher for 6 items in each of the Whole Body and

Distal Upper Extremity templates. Kappa values were 0.44 or higher for all items in the

Distal Upper Extremity template but 0.40 or higher for only 5 out of 9 items in the Whole

Body template.

The significance level (p-value) of defined kappa value was less than 0.0001 for each item except more than 0.99 for vibration (#9).

Agreement by job level of hand activity

Among ten jobs, five were classified into the low HAL job group and the rest of them classified as medium (Table 5). There was no job with a high median HAL value. Percent agreement within the low HAL group was higher for 10 items. It was substantially lower for noise level and equal or negligibly lower for the remaining items.

Kappa values for the low HAL jobs were higher for 8 items and lower for 6 items (Table 5). Most of these differences in IRRs were small and their confidence intervals overlapping. Agreement could not be compared for vibration (#15) and MMH since kappa values were undefined.

Agreement by ergonomic job analysis experience level of the raters

Percent agreement of Group A rater pairs was higher than that of Group B for 13 items (Table 6). It was lower only for 2 items, namely, elbow posture and weight in hands (#16). Percent agreement was equal between the groups for 3 items: MMH, vibration (#15), and hand observed.

Kappa values of Group A were higher than those of Group B for 9 items while they were lower only for 5 items. Differences in IRRs and their confidence intervals varied. For noise level, there was a markedly large difference in IRRs and their confidence intervals between the two groups since the 'inexperienced' rater had an industrial hygiene background and did not agree with the criteria/definitions of PATH templates. Agreement

could not be compared for vibration (#9 and #15) and MMH since kappa values were not

defined.

D. DISCUSSION

The PATH instrument has been newly revised to produce more information about ergonomic exposures to the upper extremity. In a convenience sample of hospital jobs, inter-rater reliability (IRR) was at least "acceptable" or "fair to good" for nearly all of the 18 ergonomic risk factors evaluated. Exposures to the upper extremity were generally rated with slightly higher agreement in the low HAL jobs and by the observers with more ergonomics experience.

1. Statistical methods for analyzing agreement

Inter-rater agreement is one type of reliability or reproducibility. It can be evaluated using a variety of statistical measures. Although percent agreement is still widely utilized for assessment of IRR (e.g., Johnsson et al., 2004; Warming et al., 2004), it has been criticized on the grounds that it does not account for chance agreement. ICC has been used for quantitative variables but it is influenced by the distribution, in that it assumes a normal distribution of an underlying continuous variable. Since the HAL data in this study were not normally distributed, the ICC was not a suitable IRR measure for the HAL variable.

The kappa statistic has been widely used for categorical variables, but it has the disadvantage of being highly sensitive to the marginal distributions of the ratings (Feinstein and Cicchetti, 1990). In this study, kappa had certain limitations for assessment of IRR, depending on how data were distributed in contingency tables. For

example, all of the MMH data were in one cell of the contingency table, so the kappa

value could not be calculated because it was not defined (i.e., zero in the denominator).

There were three such items for which kappa statistics could not be computed and only

percent agreement was relied on to evaluate IRR.

2. Sources of variability in agreement

The reliability of an observational technique may strongly depend on the

experience level of raters (Paquet et al., 2001); the number of exposure items to be

recorded (van der Beek et al., 1992; Paquet et al., 2001); clear definition of the variables

(Burt and Punnett, 1999; Kilbom, 1994); and the nature of the work being observed, such

as motion speed or the predictability of work activities. In general, these factors have

been discussed anecdotally but rarely examined formally. The level of experience in

exposure assessment, both within and between raters, is a factor that has been neglected

in most exposure studies (Noyes, 1994). Voskuijl and van Sliedregt (2002) reported that

job information type (e.g., behavior or work-oriented elements) and rater experience (e.g.,

experience in job analysis), among sources of variability, were shown to be highly

significant moderators of IRR. The amount of active or dynamic work has been suggested

to affect the reliability of observations for postural assessment (Burdorf et al., 1992).

In this study, the improvement in IRR after the training period suggested that there

were potential sources of variability, such as unclear posture definitions, that were

remedied by the training program and/or revisions in variable definitions. Measures of

IRR were compared with respect to job characteristics (slower vs. faster hand motions)

and level of observer experience in ergonomic job analysis to determine if either of these was a source of variability in observer agreement. In comparison of jobs with low and medium levels of hand activity (Table 5), percent agreement was better in the low HAL job group for 10 of 18 items while kappa was higher for 8 items. Although differences in kappa values varied and their confidence intervals were markedly overlapping in this study, the results overall were consistent with the prior hypothesis for at least these 8 items.

In comparison of raters of Group A versus Group B (Table 6), percent agreement of Group A was higher for 13 out of 18 items while kappa of that group was higher for 9 items. It was also noticeable that percent agreement and kappa showed consistency for these latter 9 items. Thus, as hypothesized, IRR was higher overall for observers with more ergonomics analysis experience.

Both the number of categories within items and the number of items to record per unit observation would be other potential sources of rater disagreement (van der Beek et al., 1992; Paquet et al., 2001). In this study, the IRR results were mixed across items with respect to the number of categories. For instance, the kappa statistics for leg posture, with 5 categories of postures observed, were 0.92 or higher while those for elbow posture with 3 categories were 0.45 or less (Tables 4, 5, and 6). Thus these data did not support the hypothesis that fewer categories would produce higher agreement. However, discrete leg postures may be easier to distinguish than elbow angles in a single plane. We did not directly compare more versus fewer categories for the same exposure, so this study has also not disproven the hypothesis.

Kappa values were at least 'fair to good' for all items in the Distal Upper Extremity template but only 5 of 9 items in the Whole Body template, showing that there were markedly different patterns of agreement levels between the two template items. The higher reliability for the distal UE exposures was likely attributed to the template design. The Distal Upper Extremity template was composed of simpler items (i.e., 7 dichotomous and 2 other items) so that it was easier to judge and record an observed event for those dichotomous variables. Thus we may have indirect evidence in support of the argument that fewer items will produce less error in observation.

IRR reflects the amount of random and systematic error inherent in an observational method (Gardiner et al., 2002). If IRR among observers is low, the usefulness of the observations is severely limited (Fleiss, 1981). Thus, in such a case, it would be desirable to search for and rectify sources of disagreement (Dunn, 1989). Noise level had both low percent agreement and negative kappa (Tables 4, 5, 6), except in observations made by raters of Group A (Table 6). The results and post-hoc investigation showed that the observer with no prior ergonomics experience rated the noise level differently in a systematic manner. Because negative kappa shows worse than chance-expected agreement, the noise level data collected by this rater will be dropped from future data analyses.

3. Comparison with other analyses of inter rater reliability

Percent agreement in this study ranged from 42.5% to 100% and kappa coefficients from -0.19 to 1.0 for 18 items (Table 4). The IRR level appeared to be equivalent to that

of other studies in which different versions of the PATH method were employed (In a separate project, agreement between paper-and-pencil and PDA recoding was found to be quite high (unpublished)). Buchholz et al. (1996) examined IRR in analysis of construction work for many of the original PATH codes (e.g., body postures, activity, and grasp type), which generally correspond to the whole body template items reported here. They reported percent agreement ranging from 54% to 99% during observation of two workers in a pipe-laying operation. Pan et al. (1999) used a modification of the PATH method in a retail store and reported kappa coefficients from 0.50 to 0.63 for manual material handling and trunk posture variables. Buchholz et al. (2003) assessed IRR for PATH variables (e.g., trunk, arms, legs, activities, tools used, and load handled) in another four construction job tasks; percent agreement was 81% to 100%. Schemm (2002) examined IRR using earlier paper-and-pencil versions of the current PATH instrument in a hospital setting and reported percent agreement levels ranging from 47.8% to 100%.

The IRR level of this study was equivalent to or higher than that of other studies in which different observation methods were used. Burt and Punnett (1999) evaluated 18 postures in 70 jobs in an automotive manufacturing company. They found percent agreement ranging from 26% to 99% and kappa values from 0 to 0.55. In a study using a direct observational instrument for 45 nursing patient transfers in hospital wards (Johnsson et al., 2004), percent agreement was 51% to 93% and kappa values were 0.16 to 0.77 for 16 items covering three phases of a transfer.

4. Study limitations

The IRR data in this study were obtained from ten jobs which were selected by convenience from several departments at the initial contact stage for the hospital observation. The IRR data might not be representative for all hospital jobs. In particular, no nursing jobs were included at this stage and no high HAL jobs were available. Given that agreement was inversely related to worker hand activity, agreement among observers would presumably be lower for jobs with even higher hand speed.

For items with no or very low variation, percent agreement and kappa coefficients had such extreme values that in some cases (e.g., MMH and vibration) kappa could not be computed (Tables 4, 5, and 6). For these items, percent agreement was used as a measure. However, the alternative measure is unable to account for chance agreement. The limitations of available statistical measures to analyse agreement have been discussed by others (e.g., Burt and Punnett, 1999). Intra rater reliability for the revised instrument was not assessed.

E. CONCLUSIONS

In order to examine the IRR of the newly revised PATH instrument, expert observations of 18 items (ergonomic risk factors) were conducted by four raters at a hospital. The revised instrument consisted of three templates (largely two: a Whole Body and a Distal Upper Extremity template) to record a category of each item. This study was performed as part of a large exposure assessment research work. Each worker was observed simultaneously by two of four analysts simultaneously observed across a convenience sample of 10 jobs.

A total of 443 observation pairs were used for data analyses. All ten jobs were multiple mixed tasks (non-routine jobs) and the study results were obtained as follows:

- Kappa coefficients were at least 0.44 for all 9 ergonomic risk factors in the Distal Upper Extremity template, and at least 0.40 for 5 out of 9 risk factors in the Whole Body template.

- In comparing IRRs between jobs with different levels of hand activity, kappa values for the low hand activity level jobs were higher for 8 risk factors but lower for 6 risk factors. Most of these differences in IRRs were small and their confidence intervals (95% CIs) overlapping.

- In comparing IRRs between rater pairs with experienced raters in each pair (Group A) and with one inexperienced rater in each pair (Group B), kappa coefficients of Group A were higher than those of Group B for 9 risk factors but they were lower only for 5 risk factors. Differences in IRRs and their 95% CIs varied.

These findings showed that the IRR of the revised PATH method was good. It was also shown that the IRR was higher for the jobs with less rapid hand activity (e.g., slower motion jobs) and for the raters with more experience in ergonomic job analysis.

This study shows that the newly revised PATH method can be reliably applicable to hospital work, and suggests that it can reasonably assess ergonomic exposure in any type of non-routine jobs across industries including the healthcare industry.

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Table 1
Item and category by template in the revised PATH instrument

Template	Item	Category*
Body	1. Trunk posture	1) Neutral <20°; 2) Moderate flexion ≥20° - <45°; 3) Severe flexion ≥45°; 4) Lateral bent/ twist flexed; 5) Lateral bent/ twist neutral
	2. Leg posture	1) Stand (flexion <35°); 2) Walking/ running; 3) Sitting; 4) Kneeling (1 or both knees); 5) Squat (both knees ≥80°); 6) Lunge (1 knee ≥35°); 7) Crawl; 8) Stand on 1 foot
	3. Shoulder/ arm Elevation	1) Both arms <60°; 2) 1 arm >60°; 3) 2 arms >60°
	4. Elbow posture	1) Neutral (30° – 150°); 2) Extension (>150°); 3) Extreme flexion (<30°)
	5. Weight in hands	1) <10 lbs; 2) ≥10 - <50 lbs; 3) ≥50 – <150 lbs; 4) ≥150 lbs
	6. Manual Materials Handling (MMH)	1) No MMH; 2) 1 hand; 3) 2 hands
	7. MMH action	1) No MMH; 2) Carry/ hold; 3) Push/ pull/ drag Lift; 4) Lower
	8. Noise level§	1) 0; 2) 1; 3) 2
	9. Vibration	1) None; 2) Segmental; 3) Whole-body
Hand/ forearm	10. Neutral/ gross grasp	1) No; 2) Yes
	11. Wrist/ forearm Deviation	1) No; 2) Yes
	12. Pinch grip	1) No; 2) Yes
	13. Keyboarding	1) No; 2) Yes
	14. Hand/ forearm contact stress	1) No; 2) Yes
	15. Vibration	1) No; 2) Yes
	16. Weight in hands	1) <10 lbs; 2) ≥10 - <50 lbs; 3) ≥50 – <150 lbs; 4) ≥150 lbs
	17. Hand observed	1) Right; 2) Left
Hand activity	18. Hand activity level (HAL)	Eleven categories ranging from 0 to 10 with verbal anchors: 0 (hands idle most of the time; no regular exertions); 2 (consistent, conspicuous, long pauses); 4 (slow steady motion; frequent pauses) 6 (steady motion; infrequent pauses); 8 (rapid steady motion; no regular pauses); and 10 (rapid steady motion; difficulty keeping up)

* The category of 'Not observed/not sure' in each item is omitted.

§: Noise levels, for example, are referred to communication interference as a barrier: 0 – Silent or normal level background noise; 1 – Background noise interferes with perception (possible to hear, but with increased volume); and 2 – Person standing nearby must shout to be heard.

Table 2

Characteristics of raters' major and experience

Rater	Major in highest degree	Years of experience*	
		Ergonomic job analysis	Occupational safety and health
A	Public health/occupational health and International health (MPH)	1.5	14
B	Industrial hygiene/occupational ergonomics (MS)	3	13
C	Occupational health (MPH) Occupational ergonomics (MS)	3.5	11
D	Industrial hygiene (MS)	0.2	3

* Experience years as of February 1st, 2003 (data collection began on July 9th, 2003).

Table 3

Job title and rater pair in PATH observations

Job title	Rater pair	Number of observation pairs	Subject
Cat scan supervisor	BC	22	S1
Receptionist	BC, BD	86	S2, S3, S4
Radiology technician I	CD	27	S5
Radiology technician II	AB, AC, BC	35	S6
Human resources assistant	AD	39	S7
Nuclear medical supervisor	BD	60	S8
Nuclear medical technician	BC	79	S9
Ultrasound supervisor	BD	26	S10
Ultrasound clinical coordinator	BD	54	S11
Benefits specialist	AB	15	S12
Total		443	

Table 4

Inter rater reliability for each item in PATH observations. 95% confidence interval (95% CI) and significance are shown for kappa

Item	Inter rater reliability (n= 443 observation pairs)			
	% agreement	Kappa		
		Coefficient *	95% CI	Classification †
1. Trunk posture	74.5	0.53	0.46 ~ 0.60	Fair to good
2. Leg posture	96.3	0.94	0.91 ~ 0.97	Excellent
3. Shoulder/arm elevation ‡	87.8	0.66	0.55 ~ 0.76	Fair to good
4. Elbow posture ‡	79.7	0.40	0.27 ~ 0.53	Fair to good
5. Weight in hands ‡	99.3	0.40	-0.15 ~ 0.94	Fair to good
6. Manual materials handling (MMH)	100	- §	-	-
7. MMH action	98.8	0.37	0.01 ~ 0.73	Poor
8. Noise level ‡	42.5	-0.19	-0.26 ~ -0.11	Poor
9. Vibration	99.5	0	-	Poor
10. Neutral/ gross grasp	72.2	0.44	0.36 ~ 0.53	Fair to good
11. Wrist/ forearm deviation	74.8	0.50	0.41 ~ 0.58	Fair to good
12. Pinch grip	87.3	0.72	0.65 ~ 0.79	Fair to good
13. Keyboarding	95.9	0.83	0.75 ~ 0.91	Excellent
14. Hand/ forearm contact stress	87.2	0.60	0.51 ~ 0.70	Fair to good
15. Vibration	100	1.0	-	Excellent
16. Weight in hands ‡	98.8	0.44	0.01 ~ 0.88	Fair to good
17. Hand observed	100	1.0	-	Excellent
18. Hand activity level ‡	75.3	0.65	0.58 ~ 0.71	Fair to good

* Significance: p< 0.0001 for each kappa coefficient shown, except for vibration (#9) (p>0.99).

† Classification of weighted / unweighted kappa (Fleiss, 1981): poor agreement beyond chance for <0.4; fair to good agreement beyond chance for 0.4 - 0.75; excellent agreement beyond chance for >0.75.

‡ Ordinal variable for which weighted kappa was calculated.

§ Undefined (zero in the denominator).

Table 5

Comparison of inter rater reliability between jobs with low and medium hand activity levels (HAL). 95% confidence interval (95% CI) and significance are shown for kappa

Item	Low HAL job † (n= 259 observation pairs)			Medium HAL job † (n= 184 observation pairs)		
	% agreement	Kappa Coeff. *	95% CI	% agreement	Kappa Coeff. *	95% CI
1. Trunk posture	77.0	0.54	0.45 ~ 0.64	71.0	0.51	0.4 ~ 0.61
2. Leg posture	94.8	0.92	0.88 ~ 0.96	98.3	0.97	0.93 ~ 1.0
3. Shoulder/arm elevation ‡	90.0	0.69	0.55 ~ 0.83	84.7	0.62	0.46 ~ 0.77
4. Elbow posture ‡	79.5	0.39	0.19 ~ 0.58	79.9	0.41	0.22 ~ 0.59
5. Weight in hands ‡	100	1.0	-	98.3	-0.01	-
6. Manual materials handling (MMH)	100	- §	-	100	- §	-
7. MMH action	99.6	0.75	0.40 ~ 1.0	97.7	-0.01	-
8. Noise level ‡	32.5	-0.45	-0.53 ~ -0.37	56.4	0.17	0.07 ~ 0.27
9. Vibration	99.6	0	-	99.4	0	-
10. Neutral/ gross grasp	75.9	0.50	0.39 ~ 0.61	66.7	0.34	0.21 ~ 0.47
11. Wrist/ forearm deviation	76.6	0.52	0.41 ~ 0.63	72.1	0.42	0.29 ~ 0.56
12. Pinch grip	86.8	0.70	0.61 ~ 0.80	88.0	0.74	0.64 ~ 0.85
13. Keyboarding	97.9	0.75	0.54 ~ 0.96	92.9	0.82	0.72 ~ 0.92
14. Hand/ forearm contact stress	91.7	0.67	0.53 ~ 0.80	80.6	0.53	0.40 ~ 0.67
15. Vibration	100	1.0	-	100	- §	-
16. Weight in hands ‡	99.6	0.80	0.798 ~ 0.801	97.6	-0.01	-
17. Hand observed	100	1.0	-	100	1.0	-
18. Hand activity level ‡	75.2	0.58	0.48 ~ 0.69	75.4	0.63	0.54 ~ 0.73

† Job titles classified into low HAL job (Rad. tech. I, H/R assistant, Nuclear med. supervisor, Nuclear med. tech., U/S clinical coord.) and medium HAL job (Cat scan supervisor, Rad. tech. II, Receptionist, U/S supervisor, and Benefits specialist).

* p <0.0001 for each kappa coefficient shown, except for noise level (p=0. 0015) in the medium HAL group and others
   (p>0.88 each): vibration (#9) in the low HAL job, weight in hands (#5 and #6), MMH action, and vibration (#9) in the
   medium HAL job.

‡ Ordinal variable for which weighted kappa coefficient was calculated.

§ Undefined (zero in the denominator).

Table 6

Comparison of inter rater reliability between rater pairs with experienced raters in each pair (Group A) and with one inexperienced rater in each pair (Group B). 95% confidence interval (95% CI) and significance are shown for kappa

Item	Group A † (n= 185 observation pairs)			Group B † (n= 258 observation pairs)		
	% agreement	Kappa		% agreement	Kappa	
		Coeff. *	95% CI		Coeff. *	95% CI
1. Trunk posture	82.3	0.68	0.58 ~ 0.77	68.8	0.42	0.33 ~ 0.52
2. Leg posture	97.8	0.96	0.93 ~ 1.0	95.2	0.92	0.88 ~ 0.96
3. Shoulder/arm elevation ‡	90.0	0.75	0.61 ~ 0.88	86.2	0.56	0.41 ~ 0.71
4. Elbow posture ‡	77.7	0.33	0.14 ~ 0.53	81.2	0.45	0.27 ~ 0.62
5. Weight in hands ‡	99.4	0	-	99.2	0.50	-0.1 ~ 1.0
6. Manual materials handling (MMH)	100	- §	-	100	- §	-
7. MMH action	98.9	0	-	98.8	0.50	0.1 ~ 0.90
8. Noise level ‡	96.7	0.86	0.74 ~ 0.97	3.20	- 0.59	- 0.73 ~ - 0.46
9. Vibration	100	- §	-	99.2	0	-
10. Neutral/ gross grasp	74.4	0.49	0.36 ~ 0.62	70.5	0.40	0.28 ~ 0.52
11. Wrist/ forearm deviation	79.1	0.59	0.47 ~ 0.70	71.6	0.43	0.32 ~ 0.55
12. Pinch grip	93.7	0.87	0.79 ~ 0.94	82.5	0.60	0.49 ~ 0.71
13. Keyboarding	98.3	0.93	0.85 ~ 1.0	94.0	0.74	0.61 ~ 0.87
14. Hand/ forearm contact stress	88.4	0.59	0.43 ~ 0.75	86.3	0.61	0.49 ~ 0.73
15. Vibration	100	- §	-	100	1.0	-
16. Weight in hands ‡	98.3	0	-	99.2	0.67	0.36 ~ 0.97
17. Hand observed	100	1.0	-	100	1.0	-
18. Hand activity level ‡	84.2	0.79	0.71 ~ 0.86	68.9	0.51	0.41 ~ 0.60

† Group A: rater pairs AB, AC and BC; Group B: rater pairs AD, BD, and CD.

* Significance: p <0.0001 for each kappa coefficient shown, except for items (p>0.99 each): weight in hands (#5 and #16) and MMH action in the same experience group while vibration (#9) in the different experience group.

‡ Ordinal variable for which weighted kappa coefficient was calculated.

§ Undefined (zero in the denominator).

CHAPTER III.

BIOMECHANICAL EXPOSURE TO UPPER EXTREMITY MUSCULOSKELETAL DISORDER RISK FACTORS IN HOSPITAL LABORATORIES

A. INTRODUCTION

Hospital lab work is primarily comprised of the performance of clinical tests on patient specimens (e.g., blood, urine, or tissue). Such tests frequently consist of various procedures for which multiple tasks are conducted by lab workers in repetitive hand activities and/or non-neutral upper extremity postures. Ergonomic risk factors for upper extremity musculoskeletal disorders (UEMSDs) have been studied in general by a number of researchers. The risk factors in lab workers include repetitive or prolonged activities, non-neutral postures, and forceful exertions (Bjorksten et al., 1994; Fredriksson, 1995; NIOSH, 1996; David and Buckle, 1997).

According to the US Bureau of Labor Statistics (BLS, 2002), disorders associated with repeated trauma (RTD) accounted for 65% of the total occupational illness cases in private industry in 2001. In the same year, the RTD incidence rate per 10,000 full-time

workers was 42.0 in the medical and dental laboratory sector, which was the highest rate

in the health services industry and was about twice as high as the average rate (23.8) of

private industry. In general, lab workers have been at a high risk of developing work-

related UEMSDs (disorders of the muscles, tendons, ligaments, bones, and peripheral

nervous system) that are associated with risk factors in lab work.

In epidemiologic studies, ergonomic exposure is often characterized by exposure

variables such as job title, work type or job task. Job title is the frequently used exposure

variable (e.g., Punnett, 1985; Hagberg, 1992; Burdorf, 1992 and 1995); work type, such

as repetitive work (Latko et al., 1999) or sedentary work (Feng, 1997), has also been used.

Job task has been used to organize information on ergonomic exposures (e.g., Buchholz

et al., 1996 and 2003; Paquet et al., 1999). Since modern trends in hospital lab work are

towards multi-skilling, exposures may become greatly varied. Ergonomic exposures need

to be described using a variety of organizational features (e.g., lab type) in order to

distinguish exposure profiles within lab work. However, there are still few studies that

have addressed variability within or between exposure variables in industries (Punnett

and Wegman, 2004), which includes the hospital laboratory sector.

Researchers have conducted questionnaire surveys to assess association between

the health effects of upper extremity and ergonomic risk factors in lab technicians

(Bjorksten et al., 1994; David and Buckle, 1997). One important limitation of such

studies was a potential bias in the self-reports of exposure to ergonomic risk factors. This

limitation in exposure quantification is avoided with direct observational techniques

(Buchholz et al., 1996). Direct observational techniques are reported to be useful for

describing and evaluating ergonomic exposure to risk factors (Stetson et al, 1991; Kilbom, 1994; Colombini, 1998).

PATH (Posture, Activity, Tools and Handling), a direct observation technique based on work sampling, has been used in the characterization of ergonomic exposure in different industries such as highway construction (Buchholz et al., 1996 and 2003; Paquet et al., 1999 and 2001), dairy farms (Howard, 1997), retail stores (Pan et al., 1999), fruit harvesting (Fulmer et al., 2002), and healthcare (Dybel, 2000; Rockefeller, 2002; Park et al., 2005). The PATH method has been used in the characterization of ergonomic exposure in terms of job task, time (e.g., day-to-day) and worker (Buchholz et al., 1996 and 2003; Paquet et al., 1999). Although assessment of ergonomic exposures for lab technicians (David and Buckle, 1997) and hospital workers including lab technicians (Punnett, 1987) has been recommended, job exposures in hospital lab work have still rarely been documented.

A revised PATH method, which was developed recently for healthcare workers, may permit the quantitative description of ergonomic exposure with respect to job title, work type, and work organization in hospital laboratories. Such description of exposures facilitates the identification of stressful risk factors in hospital labs. This study has specific aims as follows: 1) to develop a taxonomy that can provide information on lab organization and work operations in hospital laboratories; and 2) to assess exposure to UE postures and hand activity levels with respect to job category, level of hand activity or type of hospital laboratory.

B. METHODS

1. Study site and subjects

The study was carried out at the laboratory department of a hospital in northeastern Massachusetts, USA. The hospital was one of the participants in the PHASE (Promoting Healthy And Safe Employment) in Healthcare project at the University of Massachusetts Lowell (UML). The department consisted of eight labs within the hospital facility and also had two lab branches in the local clinics. The labs were lab chemistry, blood bank, hematology, microbiology, pathology, administration, lab support services, and night lab. The lab department had 88 workers in 2004. The workforce was on average 50 (38 for 1st shift, 9 for 2nd, and 3 for 3rd) during weekdays and 20 (11 for 1st, 6 for 2nd, and 3 for 3rd) during weekends (Appendix C).

Subjects were those who participated in the exposure assessment observations for the PHASE in Healthcare project from the lab department. They were selected by convenience and the observations were made for one subject per day over seven months. No lab workers who participated in the observations had any musculoskeletal disorders or injuries during the past 12 months prior to the observation date. Each subject signed an informed consent form which was approved by the Institutional Review Board at UML.

2. Job description

Written job descriptions and an organizational chart from the hospital provided

information on workers' qualifications, physical demands, work environment, organizational structure, and operational work processes in general. The lab department had a total of 20 job titles of which Lab Assistant had the largest population (27.3%), followed by Clinical Scientist I (22.7%), Clinical Scientist II (17.0%), Data Processing Clerk (8.0%), and Supervisor (3.4%) (Appendix C).

The lab jobs consisted of supervisor, professional scientist, technical scientist, and support personnel. Lab supervisors provided technical and administrative supervision over some lab sections or shifts. Under guidance of managers (e.g., Lab Medical Director or Lab Administrative Director), the supervisors provided performance testing in compliance with standards. They developed and upheld departmental policies and procedures and also implemented changes to promote patient care. While general supervisors conducted office work (e.g., administration), technical supervisors frequently performed lab work such as clinical tests. In the study hospital, the senior supervisor served as the lab safety officer and chaired the Lab Safety Committee, assuming in-charge responsibility in the absence of the Lab Administrative Director. Lab supervisors were often substituted for scientists or lab assistants when they were absent for some reason (e.g., sick or vacation time).

Professional scientists largely consisted of Lead Clinical Scientists and Clinical Scientist II. Lead Clinical Scientists assisted with the technical functions of a lab section under the general supervision of the supervisor. They conducted clinical testing and related technical operations within established departmental policies and procedures. They substituted for supervisors if necessary and provided direct supervision to staff as assigned. Clinical Scientist II acted with limited supervision to perform a wide variety of

test procedures according to departmental policies. They set up and operated lab instrumentation and conducted related technical activities. Also, they collected specimens for lab testing.

Technical scientists mainly consisted of Clinical Scientist I who acted with supervision of lab supervisory personnel or professional scientist in order to perform a variety of test procedures. They set up and operated instrumentation and performed related technical activities. On a daily basis, the clinical scientists conducted instrument maintenance and quality control testing according to established procedures as required. They collected blood and other patient samples for lab testing as well.

The support personnel consisted of support services and administration staffs in this study. Support services staffs included Coordinator, Support Services Leader, Lab Stock Technician, Data Processing Clerk, and Lab Assistant. Under the general guidance of the Support Services Coordinator, the Support Services Leader directed Lab Assistants who performed blood collection and specimen delivery to the lab, and the Lab Stock Technician performed functions related to order requisitioning, inventory control, and central storage in the lab department. Some Lab Assistants conducted technical tasks such as specimen processing and gross examination of patient tissue. Administrative personnel assisted the Lab Administrative Director.

3. Taxonomy of hospital laboratory work

This study attempted to construct a taxonomy (hierarchical classification system) to describe laboratory work in the hospital setting. The lab department consisted of a

number of labs, and each lab was broken into a series of operations. An 'operation' was

defined as a process in which a group of tasks or activities were routinely or non-

routinely conducted. Operation was determined in consideration of functional and/or

practical aspects as documented in one literature (Drury et al., 1987) and as previously

defined in another (COHP, 1995; Moir et al., 2003).

In the study lab department, specimen processing was a part of the lab chemistry

section, but it was separately classified as a lab in this study since specimen processing

often functions as an independent section in the hospital industry. The night lab was not

included in the taxonomy since all labs of the lab department were not run during the

night (i.e., 2nd and 3rd shifts). It was assumed that the taxonomy would be a hierarchical

or systematical classification that could be used to describe the characteristics of lab

organization and work operations in a hospital setting.

Information for constructing the taxonomy was obtained from the facility

documents (e.g., organization chart and job description), checklists used for the PHASE

project and this study, and interviews with workers. When information on specific work

operations was unclear or insufficient, a supplemental approach such as video-record

examination or direct observation was used. For example, a video was recorded for a lab

assistant in the specimen processing in order to examine an operation. The lab assistant

was selected by convenience, assuming that the assistant was a typical lab worker

(volunteers were sought from different job titles but not successful due mainly to their

rejections). The video was recorded for over 30 minutes while the worker was typically

performing an operation (i.e., post-sample processing) with various tasks (e.g., pipetting

or video display unit work).

The taxonomy was repeatedly revised on the basis of both oral discussion (with a supervisor in the facility and UML researchers who had experience in the clinical lab work) and literature review.

4. Data collection

Materials

Two checklists, "Cover Sheet" and "Super Cover Sheet," were developed for healthcare workers and used as supplementary tools in the PHASE project (Appendix D). The Cover Sheet included data such as demographic information of the worker observed, amount of time spent in tasks, work conditions (e.g., seasonal variation of workload and rest/recovery time), body support (e.g., seated with/without support), and work environment factors that might vary from day to day. The Super Cover Sheet focused on characteristics of job title such as types of work routinization and levels of safety and health responsibility that are likely to be stable over time.

A lab checklist, which was developed for this study, was used to supplement the project checklists for further information (Appendix D). The information included work operations, tasks, activities, lab rotation, tool use, workstation dimensions, and lab organization. Ergonomic risk factors of interest were checked as well. The lab checklist was revised through pilot tests and literature review.

A revision of PATH method, personal digital assistants (PDAs), a personal computer (i.e., authoring workstation), a video camera, and stopwatch were employed. The revised PATH consisted of three templates in which each template had different

numbers of items: 9 items in 'Body', 8 items in 'Hand/Forearm,' and 1 item in 'Hand Activity' templates (Table 1 and Appendix A). Each item has a number of categories that ranged from two to eleven. The Body template was designed to capture whole body postures including shoulder (3 categories) and elbow postures (3 categories) at a single point in time. The Hand/Forearm template was designed to collect distal upper extremity risk factors in a single observation after the Body template. The risk factors included wrist/forearm deviation (2 categories), neutral/gross grasp (2 categories), and pinch grip (2 categories). The Hand Activity template was designed to determine hand activity level (Latko et al., 1997) through a continuous 15-second observation. The hand activity level was scored as an integer from 0 to 10.

The PDA (Toshiba, Pocket PC e310 or e410) was used to record PATH data onsite. Electronic versions of the three templates were created using InspectWrite™ software (Penfact Inc., USA) and loaded onto the PDA. The personal computer (authoring workstation) was used to transfer PATH data from PDAs and to store exposure data. The stopwatch or digital watch was used to standardize the time intervals.

PATH data collection

Two observers who completed a 30-hour PATH training program individually collected PATH data in the lab department. The walkthrough and interview were first done in the work area where each worker was to be observed for the day. A brief discussion was held with the worker during downtime or breaks. Checklists were primarily filled out during the walkthrough and interview.

One observation was made within 90 s in which the 45-30-15 second frame was designed for the three component templates. For each observation, with a self-conceived cue (e.g., 4, 3, 2, 1, Start), an observer began to capture exposure at the very moment of the cue "Start" and then input data into the Body template within 45 s. The observer, with a second cue, captured and input exposure data into the Hand/Forearm template within 30 s after the first template. With a third cue, the observer continuously observed the target worker for 15 s and then input data into the Hand Activity template at the end of a fourth self-conceived cue (e.g., 4, 3, 2, 1, Stop). The next observation commenced immediately following another initial self-conceived cue.

An observation was defined as one record for which one category of each item was observed and recorded over the three PATH templates for 90 s. Participating workers were observed throughout the observation periods. An observation period was defined as a work shift during which a set of PATH observations was collected from one subject for up to several hours. Each observation period had a different number of observations. Six workers were observed twice at different conditions such as date, workstation, lab section and/or observer so that each observation period was independently treated even though it might have been obtained from an identical subject.

PATH observation data were input into the electronic templates of a PDA by touching the screen with the stylus pen. In this way, PATH observations were made while the worker typically worked onsite. Prior to every observation period, the PDA was fully recharged and the clock was checked.

For each item of the Body template (e.g., shoulder/arm or elbow), one of three categories was recorded as the worst case during observation. For each dichotomous item

of the Hand/Forearm template, observers recorded either category (Yes or No) for the dominant hand of the subject. A category of the wrist/forearm deviation item was recorded as "Yes" when the wrist was clearly flexed, extended, or deviated (radial or ulnar), or when the forearm was pronated or supinated. A category of the neutral/gross grasp item was recorded as "Yes" when the subject used the entire hand for lifting, lowering, pushing, pulling, holding, or operating something in a power grasp position or when the hand is not used or in a neutral position. For pinch grip, a category was recorded as "Yes" when only the fingers and/or thumb were used for handling an object.

During PATH observation, each item was assumed to be independent of other items. Observers marked "No" for neutral/gross grasp and "Yes" for pinch grip at the moment when one subject handled an object (i.e., a computer mouse). However, observers recorded "No" for neutral/gross grasp and "No" for pinch grip at the moment when the subject entered data on a keyboard of personal computer, analyzing system, or calculator. When the neutral/gross grasp category was recorded as "Yes," the category was mutually exclusive of the pinch grip category.

5. PATH data management and analysis

Data management

PATH data were transferred into the authoring workstation from the PDA. The data were visually reviewed for errors, manually cleaned, and stored for future analyses. Data in checklists were checked and manually entered into the authoring workstation. Of the 18 PATH items (ergonomic risk factors) collected for each observation, only 6 risk

factors, i.e., 5 UE postures (shoulder/arm, elbow, wrist/forearm deviation, neutral/gross grasp, pinch grip) and hand activity level (Latko et al., 1997 and 1999), were used for this study.

In an attempt to characterize the features of lab work in the study hospital laboratories using the variable of 'operation' in the taxonomy, the raw data of 'amount of time spent in tasks' collected through the Cover Sheet checklist were managed to estimate the frequency of exposure to each operation (i.e., percent time spent in each operation). The raw data were classified into operations for each lab by the observer who collected the original information on the Cover Sheet (for data quality, the two observers repeatedly discussed about definition and classification of operation over the estimation period). The exposure estimates were averaged for each operation, assuming that the lab workers typically conducted their work for 8 hours per day.

Data analysis

For each observation period, the frequency of exposure to UE postures was estimated as the percentage of observations in each category of shoulder/arm, elbow, wrist/forearm deviation, neutral/gross grasp, and pinch grip postures.

The hand activity level (HAL) of each observation was stratified into three ranges: Range 1(0 – <3.3), Range 2(3.3 – <6.7), and Range 3(6.7 – 10), and then the stratified HAL data were used to estimate the exposure frequency (i.e., percent of observations in each HAL range) for each observation period.

The mean exposure frequency estimates were compared using analysis of variance (ANOVA) or t-test with respect to exposure variables (job category, level of hand activity

or type of laboratory). Each of the exposure variables was classified into components. First, three job categories were determined for the hospital lab workers based on the "2000 Standard Occupational Classification (SOC) System" (US DOL, 2004) and the "Census 2000 Special EEO File" (US EEOC, 2004): professional, technician, and support worker. Professional and technician were defined as those who primarily conducted clinical tests or examinations for patient specimens: a professional was one who had at least BA (Bachelor of Arts) or BS (Bachelor of Science) degree while a technician was one who had two years of college courses or equivalent education. A support worker was defined as one who conducted administrative or supportive work in the hospital lab department. In this study, supervisor and professional scientist were classified as professional, and technical scientist was classified as technician. Support staffs were classified as support worker even though some of Lab Assistant personnel worked as technician in the hospital lab department.

Second, hand activity level was determined by classifying the median HAL value for each observation period as "low" if 0 to < 5.0 or "high" if 5.0 to 10.

Third, seven lab types were determined based on functional and operational features in the hospital industry in general: Lab I for specimen processing; Lab II for lab chemistry; Lab III for hematology; Lab IV for blood bank; Lab V for microbiology; Lab VI for pathology and histology; Lab VII for administrative office and support services.

It was hypothesized that the exposure frequency (percent of observations) would be different with respect to job category, level of hand activity, or type of lab. In the assessment of such exposure frequency, the observation period was regarded as the unit of analysis, assuming that each observation period was independent regardless of job

category, hand activity, or lab type. The category of 'Not sure and not observed' in each

item was treated as a missing value in the data analyses.

Data were analyzed using SAS 9.1 (SAS Institute Inc., 2003).

C. RESULTS

1. Taxonomy of hospital laboratory work

A taxonomy was constructed as shown in Table 7. The taxonomy consisted of two to four operations for each laboratory. The laboratories were specimen processing, laboratory chemistry, hematology, blood bank, microbiology, pathology, administration, and laboratory support services.

The following description is given for the specimen processing as one of the taxonomy examples. Once a set of specimens was received in the lab, it was unpacked, examined, registered, and delivered to a lab where the specimens were tested and reported. Samples were preliminarily prepared using tools (e.g., pipette) or instruments (e.g., centrifuge or stirrer) before delivery. The work cycle, procedure, and duration depended on the type or amount of specimens. During observations, lab workers normally conducted the specimen processing in stand and walking positions at most of the time. Hand activities were often performed during sample handling, typing, and labeling. Major tasks in the specimen processing were manual sample handling, keyboarding at a video display unit, pipetting, instrument operation, labeling/writing, and phone. The specimen processing had three operations: pre-sample processing, sample processing, and post-sampling processing. Each operation in the study laboratories is described in Table 7.

Using the variable of 'operation' in the taxonomy, an attempt to characterize the features of laboratory work was made. In the data of PATH Cover Sheet checklist, the

frequency of exposure to each operation varied within and across labs (Table 8), and the highest percent of time in an operation was 95% for 'manual sample preparation' in the pathology lab. The frequencies of exposure to manual work operations rather than automated operations were noticeably high across the labs.

2. Exposure to biomechanical risk factors

A total of 18 (15 female and 3 male) full time lab workers were observed in this study and ages ranged from 22 to 62. All but two of the workers, one each from the 2nd and 3rd shifts, worked on the 1st shift.

A total of 24 PATH observation periods (18 laboratory workers in 11 job titles) were obtained for each risk factor for upper extremity (UE) postures and hand activity levels (HALs) in the hospital laboratories (Tables 8 and 9). Twenty one (87.5%) out of 24 observation periods covered the worker's right hand for the Hand/Forearm template. The PATH observation periods were composed of 2,165 observations for shoulder and elbow postures, and of 2,186 observations for hand/forearm postures as well as HALs. The observation durations ranged from 105 minutes to 380 minutes for 11 (55%) job titles.

Upper extremity posture

The mean percent of observations in each posture (e.g., neutral and non-neutral for shoulder/arm) is shown in Table 10 and Figure 3. The highest exposure frequency of non-neutral postures was 73% for wrist/forearm deviation, followed by 71% for neutral/gross grasp and 49.3% for pinch grip. The exposure frequencies for non-neutral shoulder/arm

and elbow postures were 13.5% or less.

Repetitive hand activity

The 2186 observation data of the HAL variable (numeric scales) were not normally distributed and the overall mean HAL was 4.7 on a 0-10 scale (Figure 4). The highest score frequency among 11 integers of the 0-10 scale was 30.7% for 6 (steady motion and infrequent pauses), followed by 17.8% for 4 (slow steady motion and frequent pauses) and 11% for 7. Mean percent of observations for each stratified HAL range was highest as 60.8% for Range 2 (3.3 - <6.7), followed by 21.9% for Range 1(0 - <3.3) and 17.3% for Range 3 (6.7 – 10)(Table 11 and Figure 5).

3. Comparison of measures by exposure variable

Non-neutral upper extremity posture

The mean percent of observations in each of the non-neutral UE postures was compared among components of exposure variables (job category, hand activity, and lab type) (Table 12 and Figure 6). Mostly, exposure frequency differences for nonneutral UE postures were not significant among components of each exposure variable (p>0.05). However, difference in pinch grip between high and low hand activity was significant (p<0.05).

Repetitive hand activity level

Comparisons of exposure frequencies on three HAL ranges were made with regard

to job category and lab type components (Table 13 and Figure 7). Exposure frequencies

for each HAL range were not significantly different among components of each exposure

variable (p>0.05).

D. DISCUSSION

1. Findings and implication

An exposure frequency (mean percent of observations) for each biomechanical risk factor was estimated for each of 24 observation periods (work shifts) in hospital laboratories. Among non-neutral UE postures, the highest exposure frequency was 73% for wrist/forearm posture. More than 60% of the work shifts had a median HAL value in the moderate range (3.3 to <6.7). Pinch grip frequencies were significantly higher in jobs with higher median HAL scores.

Using both the variable of 'operation' in the taxonomy and information on 'time spent in tasks' from the Cover Sheet checklist, the frequency of performance for each 'operation' was estimated (Table 8). It was found that manual work operations rather than automated operations were most predominant across labs.

In this study, exposure frequencies were markedly high for non-neutral distal UE postures but not for non-neutral shoulder/arm and elbow postures. On a 0-10 HAL scale, the highest score frequencies were 30.7% for 6 (steady motion and infrequent pauses), 17.8% for 4 (slow steady motion and frequent pauses) and 11% for 7. It is noticeable that such levels of exposure to HAL scales were found in the study laboratories in which the exposure frequencies for 'manual work operations' were more highly prevalent than those of 'automated work operations' over the labs. These findings imply that lab workers performed hand activities or manipulative tasks with somewhat highly repetitive motions and awkward posture of the hand and fingers while their shoulders and elbows

remained in the range of normal positions. In fact, a number of lab workers were observed to most likely perform multiple activities in such motions and postures during pilot field observations in the same study lab department. It is concerned that, although lab workers are in the normal range of shoulder and elbow postures, their exposure to steady repetitive motions in combination of non-neutral hand and finger postures for a prolonged time duration could lead to a significant exposure risk for repeated trauma disorders. Even though the incidence rate per 10,000 full-time workers for RTDs in medical and dental lab workers has been reported to be about twice higher than the average rate in private industry in 2001 (BLS, 2002), it is true that laboratory work has been rarely attention compared to works with high repetition and/or forceful exertion in other industrial sectors. In order to effectively minimize musculoskeletal problems in laboratory work, the specific effects of the above exposures (e.g., repetitive motion close to the center of the normal range) should be understood (Punnett and Wegman, 2004).

Comparison results of exposure outcome measures varied, depending on risk factor and exposure variable. Among the comparison results, exposure frequency differences were only significantly high between high and low components of hand activity for pinch grip whereas differences were not significantly high for the rest of risk factors across exposure variables. These facts are probably related with exposure assessment approach (e.g., methodological issue as described below) which was employed in the current study. In comparing exposure measures across labs, the exposure frequency of non-neutral distal UE postures was markedly lower for the lab chemistry. There is one possible explanation that the lowest levels of exposure frequency in the lab might have been attributed to the operational work processes since the PATH data were collected from lab workers who

mostly performed the automated operation rather than the manual work operation. In addition, there were a variety of differences in exposure frequency levels between the lab with the highest level and the lab with the lowest. In other words, the highest or lowest level within each risk factor (body segment or HAL range) varied depending on lab, and differences between the two extreme levels varied depending on the body segments or HAL ranges. Although exposure frequency differencies are not significant in the outcome results, the differences would lead the results away from the null hypotheses.

2. Exposure assessment and methodological issue

It is important to understand the characteristics of an exposure assessment instrument when it is employed in a study. The PATH instrument used in this study was newly revised to characterize ergonomic exposures in the healthcare industry (Park et al., 2005). The revised instrument was designed to assess ergonomic exposure comprehensively for groups of jobs across multiple departments and healthcare settings within the context of a social epidemiologic investigation.

Haslegrave and Corlett (1990) stated that there are generally two types of exposure assessments in workplace surveys: 1) entire job analysis identifies jobs within a facility that may present risk factors; and 2) in-depth analysis (e.g., task-by-task level) examines individual jobs or tasks to assess exposure to risk factors with more detail.

The entire job analysis approach can provide general features (global pictures) of ergonomic exposure for the jobs or occupations in the study population. The advantage of the entire job analysis is that it allows an assessment of multiple jobs when time is limited.

The disadvantage is that it does not allow exposures to be linked to specific work elements and therefore does not provide adequate information for intervention. Compared to the entire job analysis, the task-by-task analysis has the strength to characterize the exposures in much more specific levels of work elements such as tasks or activities. In other words, it is known that lower levels of work elements can be more favorably captured by the task-by-task rather than the entire job analysis approach. However, both approaches can miss information on certain jobs or tasks that are rarely performed or not conducted on the allocated survey date in the workplace.

The PATH sampling instrument as revised for the PHASE project was oriented towards the entire job analysis approach rather than the task-by-task approach (in fact, no information on task was collected in the subset of the PATH data). Thus, the study results, which were characterized exposure to biomechanical risk factors on an entire job analysis basis, would provide information on the general features of physical exposure risk for MSDs or injuries in the hospital laboratories.

3. Comparisons with other studies

Mean percent of observations on non-neutral shoulder/arm and elbow postures in this study was 13.5% and 10%, respectively. These exposure frequency levels seemed to be somewhat higher than those reported by others. Buchholz et al. (2003) reported 4% to 9% of frequency levels for arm postures at or above shoulder height (one or both) when the researchers evaluated the ergonomic hazards of ironwork job tasks using a version of PATH method at a highway construction site. Howard (1997) reported 5% of frequency

level for arm postures with one or both arms up when an exposure assessment study was conducted by direct observation of dairy farming work using a version of PATH method.

One possible explanation for the higher frequency levels, compared to those of other two studies above, is likely to be attributed to the difference in definition of arm postures. As one of PATH risk factors in this study, arm posture was divided into shoulder/arm and elbow postures and each posture consisted of three categories (see Table 1). In particular, when the flexion angle of one or both arms, regardless of elbow below or above shoulders, was more than 60 degrees, shoulder/arm posture was regarded as a non-neutral posture, indicating that the PATH version used in this study can provide higher frequency estimates of exposure to non-neutral arm postures.

For comparison of exposure to other variables (wrist/forearm deviation, gross grasp or pinch grip) among studies, there was lack of information on such exposure data in the literature, implying that further exposure assessment studies are needed to examine exposure to a wider variety of risk factors including distal UE postures.

4. Limitations of this study

The revised PATH version was actually used to collect PATH exposure data from multiple departments in the study hospital. This study used a subset of the PATH data in order to characterize exposure to biomechanical risk factors in the lab department of the hospital. However, it is uncertain how well the true exposure in the lab department might have been characterized by the revised PATH method. In fact, the outcome data, as a result of analyzing the subset data, might not sufficiently reflect the original purpose of

the revised PATH method. In a sense, since the PATH instrument was not designed for use in such a specific department level as the hospital lab department, the differences of exposure levels for most risk factors might not be significantly high among components of each exposure variable.

Among the three templates in the revised PATH instrument, the Body template was designed and used in collection of exposure information only for the worst case and the Forearm/Hand template was only for the dominant hand when an observer captured each exposure event during PATH observation. This indicates that the exposure levels for the whole body parts (i.e., shoulder/arm and elbow postures) might have been overestimated, and that exposure information on the non-dominant hand is not provided in this study. Furthermore, more detailed information on UE postures (e.g., flexion/extension or radial/ulnar deviation wrist angles) could not be provided since the Forearm/Hand template was designed to capture dichotomous postures only.

A number of items (risk factors) in the PATH templates were excluded in the analyses of the existing data subset. These items included trunk posture, leg posture, weight in hands, manual materials handling, noise, vibration, keyboard use, and hand/forearm contact stress. Any item on psychosocial aspects was not available. This study was restricted to characterization focused on exposure to awkward postures and hand activity levels of the UE in the study lab work.

E. CONCLUSIONS

An assessment study was conducted to characterize exposure to biomechanical risk factors in hospital laboratories. The study used a subset of PATH observation data which were collected for a large research study. The data subset was collected using a revision of the PATH method by two observers who made over 2165 observations of 24 work shifts (18 laboratory workers) over seven months. Key risk factors included non-neutral upper extremity postures and hand activity level (HAL) rating of motion speed and pause frequency (Latko et al., 1997). A taxonomy was also developed to explore information on work operation and lab organization. An exposure frequency (weighted mean percent of observations) for each risk factor was estimated for each of the observed 24 work shifts.

Lab workers were predominantly exposed to manual work operations rather than automated operations across 8 laboratories in the hospital. The highest exposure frequencies of non-neutral UE postures were 73% for wrist/forearm deviation, 71% for neutral/gross grasp, and 49.3% for pinch grip. The overall mean HAL was 4.7 on a 0-10 scale and 60.8% of the observed work shifts had HAL scores in the moderate range (3.3 to <6.7). In comparing exposure frequencies among components of exposure variables (job category, hand activity or laboratory type), differences were not significantly high for most non-neutral UE postures. However, the difference was significantly high for pinch grip posture with regard to hand activity. In comparison of the exposure frequencies for the three HAL ranges, exposure frequencies were not significantly different among components of each exposure variable (job category or laboratory type).

The results showed that there were markedly high exposures to postural strain for

the distal UE and also moderately high exposures to hand activity in the hospital

laboratories. The study suggests that assessing biomechanical exposures, in combination

with taxonomic information, can provide useful information on reduction of exposure

risks for MSDs or injuries in general lab work.

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Table 7

Taxonomy of hospital laboratory work, operation description and example work elements

in the study hospital laboratories

Lab type	Operation	Description	Example work element
Specimen processing	Pre-sample processing	Specimens are received from different places including departments of a facility, local clinics (laboratories), and residents. Specimens are registered (each accession number is assigned).	Sample manual handling (reception; capping and decapping of specimen tubes); VDU (keyboarding for registration); opening specimen bullets (a delivery box), labeling/ writing, phone
	Sample processing	Samples are preliminarily prepared using instruments (e.g., centrifuge or stirrer) or tools (e.g., pipette) before delivery. Minor testing is performed.	Sample manual handling (capping and decapping of specimen tubes); pipetting; VDU (result recording; test report); instrument use or operation; labeling/ writing; phone
	Post-sample processing	Specimens are delivered to lab sections. Using VDU to track specimens and make sure they have been properly handled	VDU (tracking, result report); sample manual handling (delivery to lab sections); phone
Lab chemistry	Automated chemistry	Placing specimens on the appropriate instrument according to the tests ordered.	Pipetting; instrument operating (sample analysis, result report); phone
	Manual chemistry	Like osmometry and acetone testing, specimens are tested manually. Blood gas samples are analyzed.	Sample manual handling (sample preparation); pipetting; labeling/ writing; phone
Hemato-logy	Automated hematology	Placing test tubes on the appropriate instrument for analysis	Instrument operating (sample analysis, result report); sample manual handling (sample preparation); pipetting; phone

	Manual hematology	CBC (complete blood count), differentials and urine microscopy are performed. Dipstick urines are performed on a Clinitek	Sample manual handling (sample preparation); pipetting; microscopy (making test slides; microscope use); VDU (result report); Instrument operating (centrifuging; sample test), labeling/ writing; phone
Blood bank	Blood testing (type, cross match, HIV)	Blood type (ABO/ RH) and cross match are tested. HIV testing is done on semi-automated equipment.	Sample manual handling (sample preparation); pipetting; Instrument operating; VDU (record results, result report); labeling/ writing; phone
	Blood bank database review	Record or review blood information in blood bank database (paperwork and statistics)	VDU (record or review database; check stock status)
Micro-biology	Automated microbiology	Tests performed on instrumentation; some biochemical tests on bacteria;	Sample manual handling (sample preparation); instrument operating; pipetting; VDU (result review and report); phone
	Manual microbiology	Agar plates are inoculated with various specimens and examined for the presence of bacteria; gram stains, ova and parasite examinations are performed. Other work (immunology/ serology) may exist.	Sample manual handling (inoculating culture plates; storage; opening and closing plates; reading plates); pipetting; microscopy (microscope use); labeling and writing; VDU (result review and report); phone
Pathology (histology, cytology)	Automated sample preparation	Tissue samples are prepared as ordered for analysis by fixation or staining	Sample manual handling (sample preparation; fixation; staining); instrument operating; VDU (result review and report); phone

	Manual sample preparation	Sample preparation includes cutting and cover mounting. During preliminary examination, samples are handled on a microscope. (Gross examination may be conducted)	Sample manual handling (cutting tissues; cover mounting); microscopy (pre-examination); instrument operating; VDU (result review and report); labeling and writing; phone
Administration	Staffing	Workforce is managed for shifts and rotation work; Supervision	VDU (data review and report); phone
	Planning and budgeting	Planning and budgeting for lab department; Coordinating with other departments	VDU (data review and report); phone
Lab support services	Phlebotomy	Blood is sampled from outpatients and inpatients by phlebotomists, Information of patients is recorded and reviewed in the databases	Specimen sampling (e.g., drawing blood); sample handling (blood rocker); VDU (record or review patient information); phone
	Specimen transport	Samples are delivered to specimen processing section (manually or mechanically)	Carrying delivery box; lifting and lowering; preparing and loading specimens to the pneumatic transport system ("the bullet")
	Material stock	Supply and storage of lab materials; Inventory and ordering	Push-pull carts; carrying lab materials; VDU (data review, material order, and report); phone
	Data processing	Information on phlebotomy work or specimen transport will be entered at PCs	Document and record review; VDU work, phone

Table 8

Mean percent time spent in each operation by laboratory type in the study hospital

laboratories

Lab type	Operation	Percent time observing in each lab (%)	Observation period
Specimen processing	Pre-sample processing	49.5	4
	Sample processing	27.0	
	Post-sample processing	13.5	
	Others	10.0	
Lab chemistry	Automated chemistry	82.0	3
	Manual chemistry	-	
	Others	18.0	
Hematology	Automated hematology	42.0	3
	Manual hematology	48.0	
	Others	10.0	
Blood bank	Blood testing (type, cross match, or HIV)	93.0	2
	Blood bank database review	-	
	Others	7.0	
Microbiology	Automated microbiology	4.3	4
	Manual microbiology	90.3	
	Others	5.4	
Pathology (histology or cytology)	Automated tissue preparation	-	3
	Manual sample preparation	95.0	
	Others	5.0	
Administration	Staffing	30.0	1
	Planning and budgeting	55.0	
	Others	15.0	
Lab support services	Phlebotomy	25.0	5
	Specimen transport	5.0	
	Material management and stock	33.0	
	Data processing	33.0	
	Others	4.0	
Total			24

Table 9

Number of PATH observations and observation period durations

Observation period	Subject*	Body observation	Hand/ forearm observation	Observation duration (min)
1	A	63	80	165
2	A	115	137	380
3	B	62	58	122
4	C	44	45	120
5	D	38	39	111
6	E	150	155	375
7	E	115	114	260
8	F	69	65	215
9	F	52	50	157
10	G	131	125	316
11	H	150	143	335
12	H	70	69	181
13	I	137	129	354
14	I	138	139	335
15	J	40	44	122
16	K	139	129	302
17	L	44	44	105
18	M	76	79	154
19	N	89	97	255
20	O	65	73	200
21	P	124	120	375
22	Q	113	111	259
23	R	63	65	153
24	R	78	76	190
Total		2165	2186	

* Subject: six out of 18 subjects were observed twice so that a total of 24 observation periods were obtained.

Table 10

Mean percent of observations on upper extremity postures in the hospital

laboratories (n=24 observation periods)

Upper extremity	Category	Mean (%)	SD
Shoulder/arm	Neutral	86.3	9.7
	Nonneutral	13.5	9.7
Elbow	Neutral	89.7	6.3
	Nonneutral	10.0	6.5
Wrist/forearm deviation	No	26.3	10.1
	Yes	73.0	10.3
Neutral/gross grasp	Yes	28.3	12.9
	No	71.0	13.0
Pinch grip	No	50.0	14.8
	Yes	49.3	14.5

Table 11

Mean percent of observations on each range of hand activity

levels (HALs) in the hospital laboratories (n=24 observation periods)

Item	Category*	Mean	SD
Hand activity level	Range 1: 0 - <3.3	21.9	11.2
	Range 2: 3.3 - <6.7	60.8	12.0
	Range 3: 6.7 – 10	17.3	10.5

Table 12

Comparison of mean exposure frequency estimates among components of each exposure variable (job category, hand activity, and

laboratory type) for each of nonneutral upper extremity (n= 24 observation periods)

Exposure variable	Component	Obs. number	Obs. period number	Mean exposure frequency (standard deviation)*, %				
				Shoulder/ Arm	Elbow	Wrist/forearm Deviation	Neutral/gross Grasp	Pinch Grip
Job category	Professional	840	10	16.4 (11.4)	10.0 (6.6)	68.9 (13.6)	65.6 (17.6)	43.6 (19.1)
	Technician	679	7	13.5 (8.1)	8.7 (5.4)	76.9 (2.8)	74.0 (5.3)	55.2 (5.2)
	Support	602	7	9.3 (8.1)	11.4 (7.8)	75.1 (8.4)	75.9 (8.3)	51.5 (11.4)
Hand activity†	Low: 0-<5.0	959	11	12.2 (9.0)	8.4 (5.0)	69.4 (11.9)	66.3 (14.9)	42.6 (16.5)
	High: 5.0-10	1162	13	14.6 (10.4)	11.4 (7.4)	76.1 (8.0)	75.1 (10.0)	54.9 (10.1)
Laboratory type	I (SP)	434	4	9.8 (10.5)	6.1 (7.7)	74.0 (9.9)	69.9 (13.5)	39.0 (18.2)
	II (Chem)	195	3	12.3 (7.7)	8.1 (5.3)	60.5 (22.0)	57.5 (25.1)	31.9 (10.3)
	III (Hema)	207	3	11.8 (5.0)	9.1 (3.6)	74.6 (4.7)	76.6 (5.1)	56.9 (9.2)
	IV (BB)	207	2	22.3 (8.9)	13.0 (8.0)	75.8 (1.4)	69.0 (3.3)	61.3 (3.6)
	V (Micro)	471	4	8.5 (3.6)	5.6 (2.6)	73.9 (6.9)	67.0 (11.3)	49.0 (9.4)
	VI (Path)	112	2	21.5 (16.7)	19.0 (4.1)	80.5 (7.8)	80.5 (17.7)	61.9 (16.8)
	VII (Suppt)	495	6	15.1 (12.6)	13.1 (6.4)	73.8 (7.9)	76.0 (7.5)	52.9 (11.8)

* p<0.05 for only pinch grip exposure frequency estimates between two components of hand activity.

† Hand activity level was categorized on the basis of the median HAL value for each observation period.

Table 13

Comparison of mean exposure frequency estimates among components of each exposure variable (job category

and laboratory type) for each range of hand activity level (n= 24 observation periods)

Exposure variable	Component	Obs. number	Obs. period number	Mean exposure frequency (standard deivation)*, %		
				HAL range 1 (0 - <3.3)	HAL range 2 (3.3 - <6.7)	HAL range 3 (6.7 - 10)
Job category	Professional	840	10	24.4 (9.5)	62.6 (13.4)	13.0 (7.6)
	Technician	679	7	20.3 (14.3)	60.9 (13.8)	18.8 (8.8)
	Support	602	7	20.0 (11.0)	58.0 (8.5)	21.9 (14.1)
Laboratory type	I (SP)	434	4	21.6 (13.5)	55.6 (9.6)	22.8 (16.3)
	II (Chem)	195	3	26.9 (7.6)	65.3 (15.6)	7.8 (8.0)
	III (Hema)	207	3	17.3 (17.4)	67.1 (14.4)	15.6 (8.7)
	IV (BB)	207	2	24.6 (20.2)	61.6 (16.9)	13.8 (3.3)
	V (Micro)	471	4	19.5 (4.6)	58.2 (10.0)	22.4 (7.8)
	VI (Path)	112	2	11.9 (3.4)	72.4 (15.5)	15.7 (12.1)
	VII (Suppt)	495	6	26.1 (11.2)	56.3 (10.8)	17.6 (10.8)

* p>0.05.
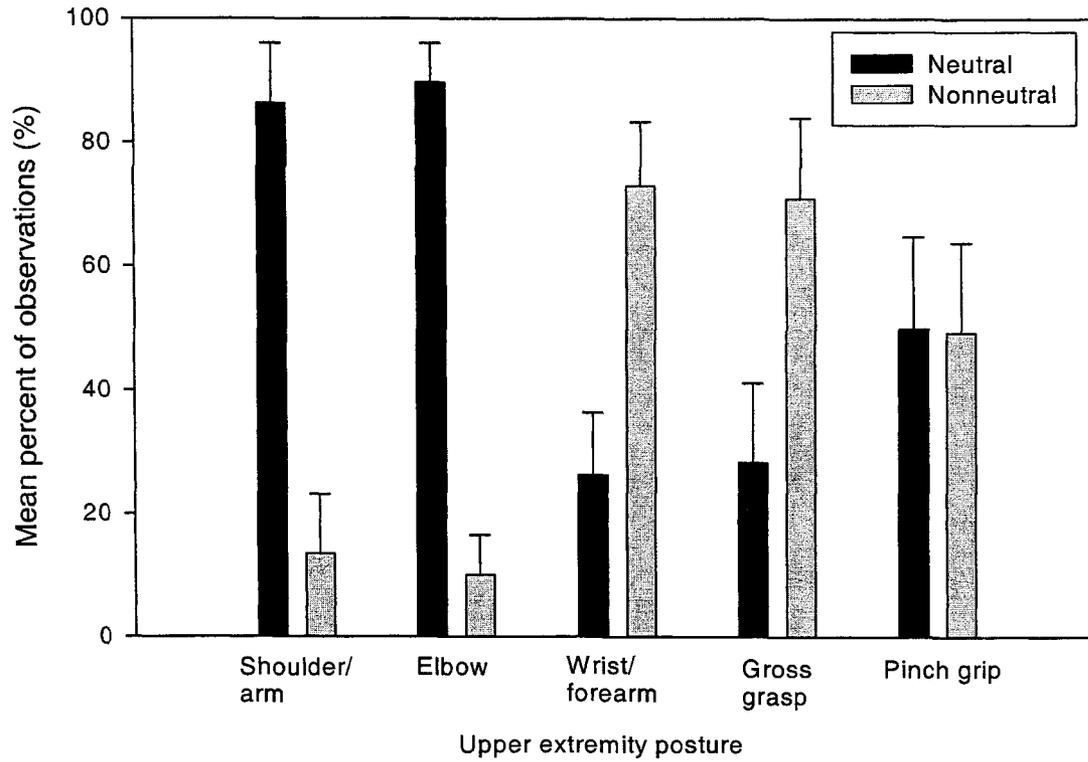
Figure 3. Mean percent of observations on upper extremity postures in the hospital laboratories (n=24 observation periods).
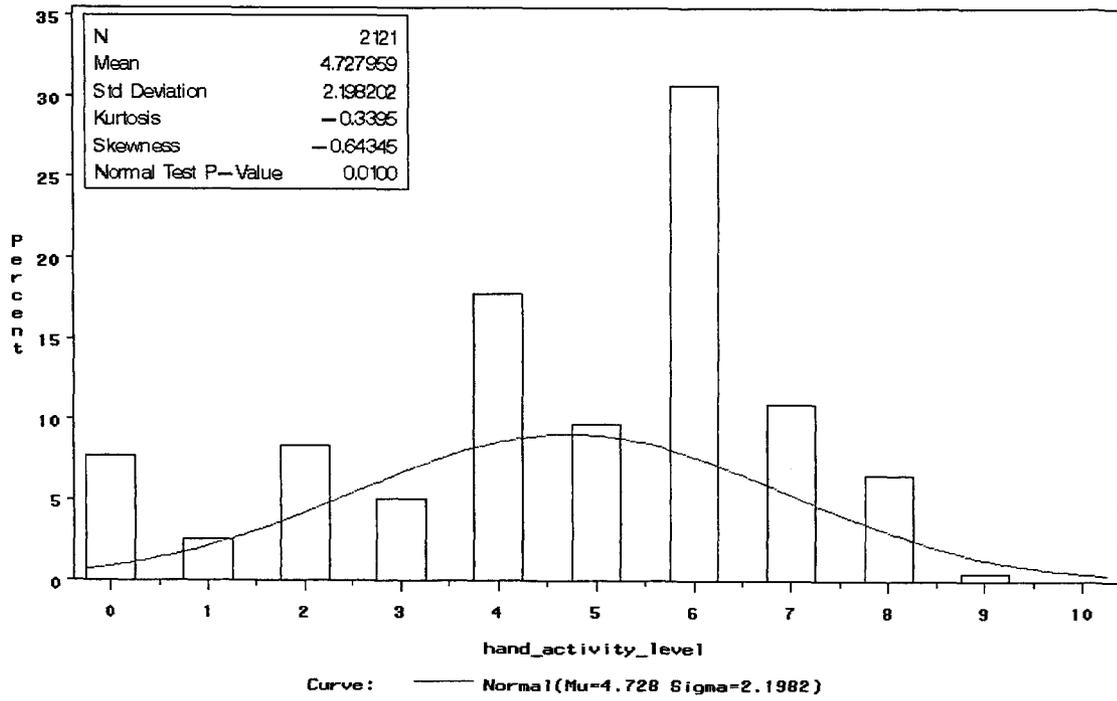
Figure 4. Distribution of hand activity level data in the hospital laboratories.
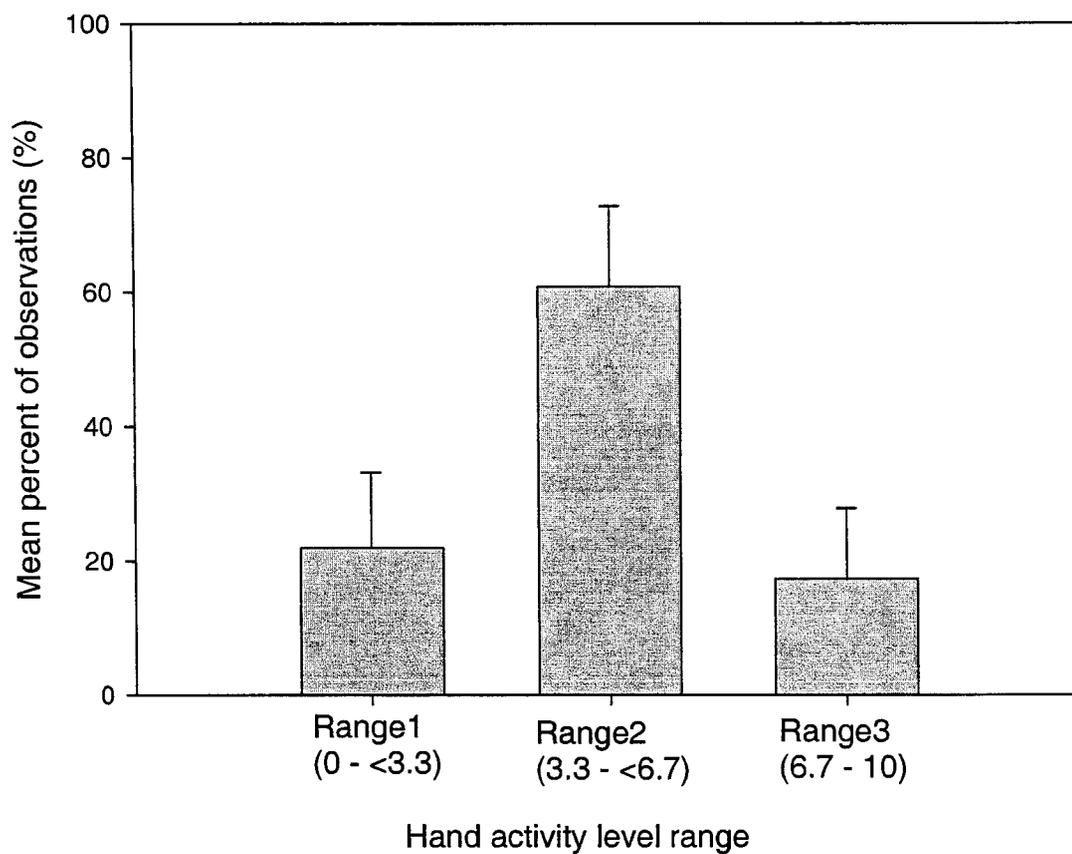
Figure 5. Mean percent of observations in each range of hand activity level (HAL) in

the hospital laboratories (n=24 observation periods).
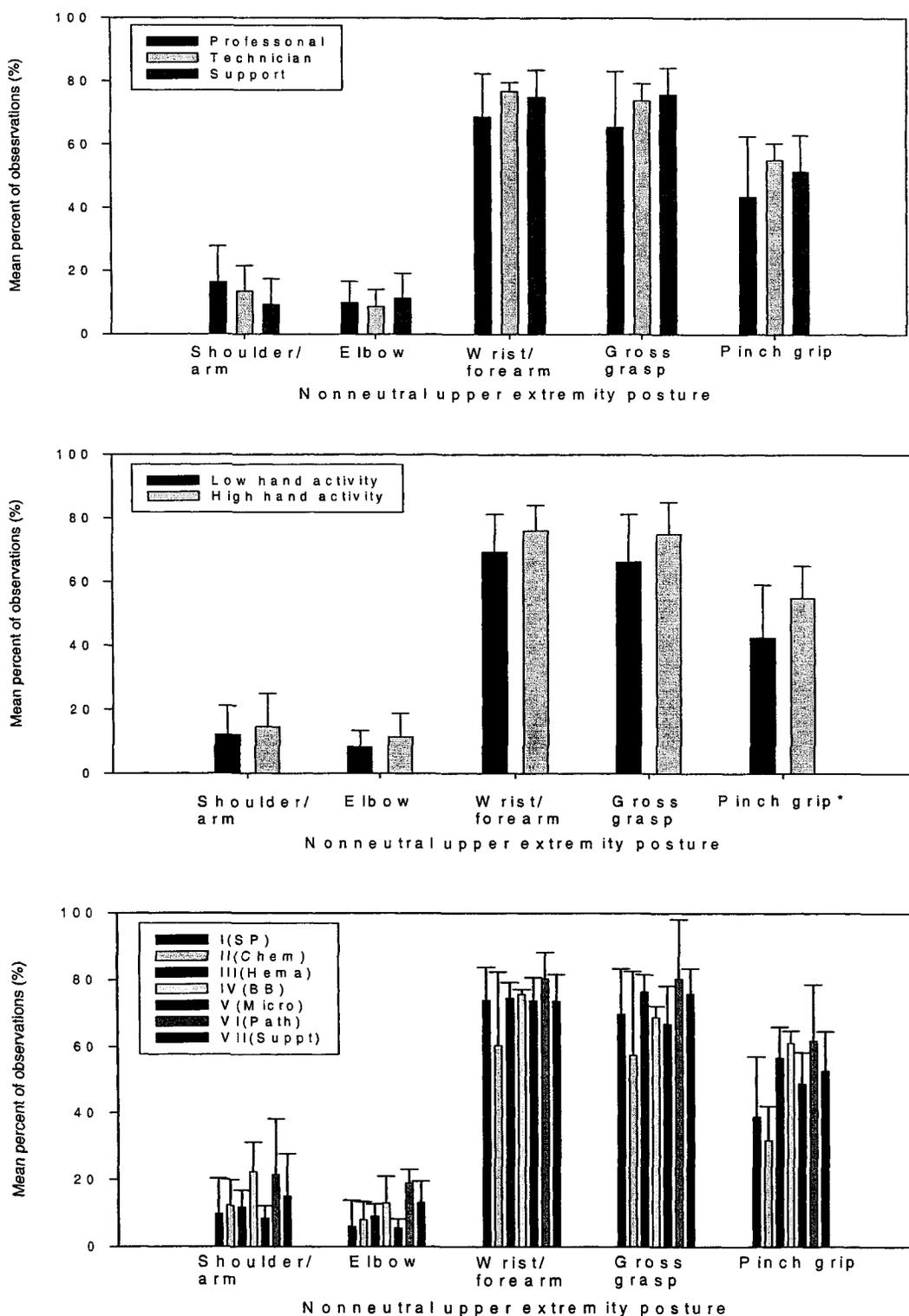
Figure 6. Comparison of mean exposure frequency estimates among components of each exposure variable, job category (top), hand activity (middle), lab type (bottom), for each of nonneutral upper extremity (n= 24 observation periods; * p<0.05 for only pinch grip between two components of hand activity).
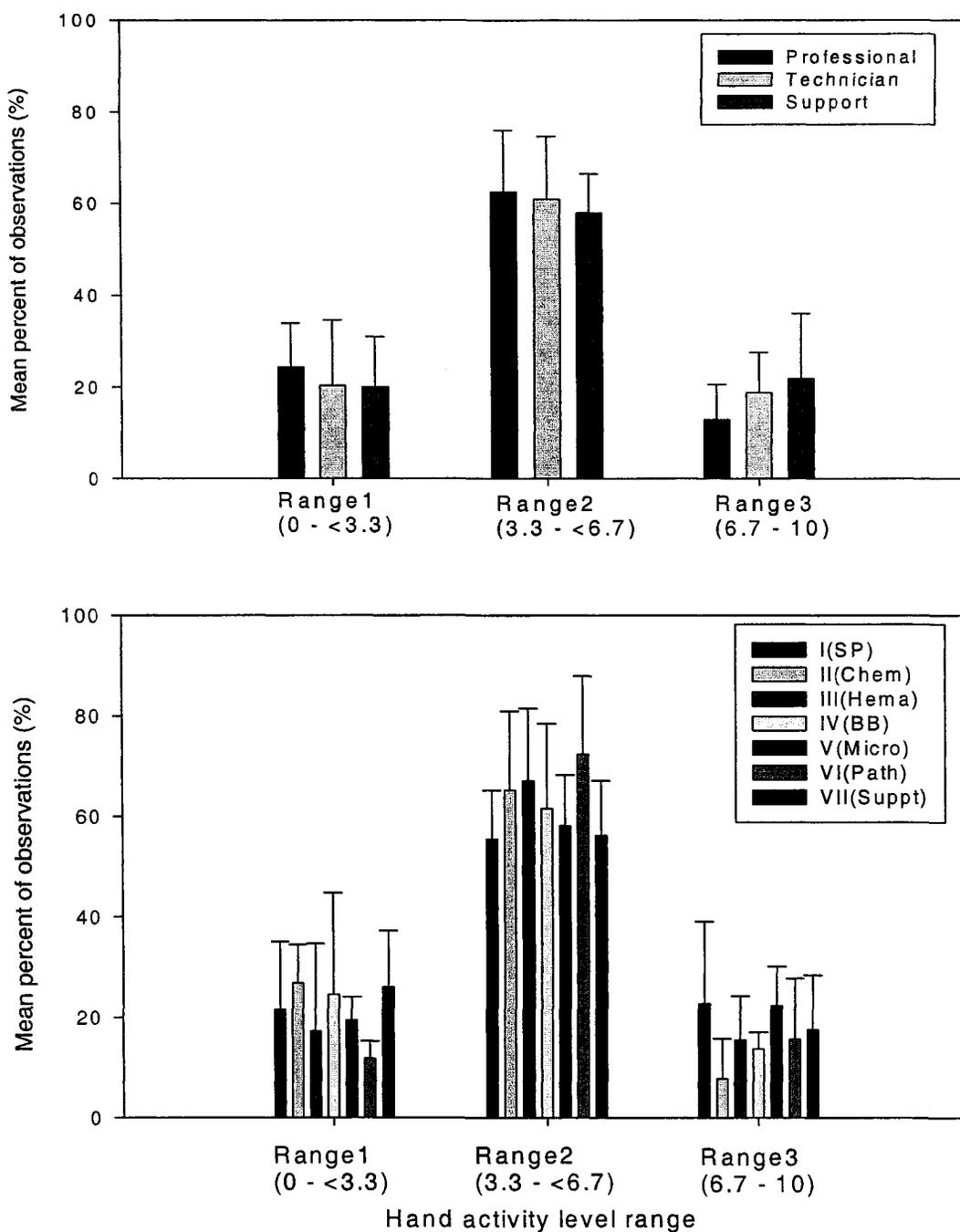
Figure 7. Comparison of mean exposure frequency estimates among components of each exposure variable, job category (top) and lab type (bottom), for each range of hand activity level (n= 24 observation periods).

CHAPTER IV.

MUSCLE ACTIVITY AND POSTURE OF THE UPPER EXTREMITY DURING SIMULATED PIPETTE WORK

A. INTRODUCTION

Pipetting is the task of transferring an exact amount of liquid from one vessel to another using a pipette, a very narrow cylinder with a valve usually operated by the thumb. A pipette operation usually consists of tipping, aspirating, dispensing, and tip ejection.

Pipette operation, which may be performed either standing or seated, involves repetitive activities of the upper extremity (UE) in combination with muscle strain and/or awkward postures. Ergonomic risk factors in pipette work have been documented by a number of researchers: 1) workstation design/work surface height (NIOSH, 1996; David and Buckle, 1997); 2) repetition, force, or posture (Bjorksten et al., 1994; Fredricksson, 1995; NIOSH, 1996; David and Buckle, 1997; Asundi et al., 2005). NIOSH (1996) conducted a survey of lab technicians who made approximately 6,000 to 11,750 hand manipulations involving pipetting per day during drug preparation or drug screening.

David and Buckle (1997) found that 68% of the pipette users identified features of the general work environment that made the pipetting task more difficult. Such features included seating-work bench interactions, insufficient/over-crowded work space, and awkward restrictions/equipment.

Fredriksson (1995) measured the maximum thumb force for pressing the pipette plunger in a power test and estimated the level of maximum voluntary contraction (MVC) in pipette use. The level of muscle activity during a pipette operation was 4.3 to 18.4% of MVC. The maximum thumb power was 7.9 kg for female and 10 kg for male lab workers and this was somewhat similar to the tip ejection force (Fox, 1999) and the peak lateral pinch strength (Mital and Kumar, 1998).

When the pipette task is repeatedly performed in non-neutral positions for a prolonged period of time, musculoskeletal soft tissues can be strained and disorders may develop. Musculoskeletal symptoms of "pipetter's thumb" have been reported in the literature (Minuk et al, 1982; Baker and Cooper, 1998).

Variations in work station dimensions can affect workers with varying anthropometries differently. Work surface height is one of the factors that have been addressed in human work for years. It is known that the work surface height can influence musculoskeletal disorder risk factors (e.g., forceful exertion and awkward posture) as well as productivity in the workplace (Ayoub, 1973). If the height of work surface is too high or too low during pipetting, it can cause adverse effects on work postures and lead to strain in the soft tissues (Kroemer and Grandjean, 1997).

General guidelines specify that the hand should be at about elbow height while working. More specific work surface height recommendations are generally based on the

type of work performed. It has been recommended that the most favorable work surface

height for handwork when standing should be: 1) 5 to 10 cm above elbow height for

precision work; 2) 10 to 15 cm below elbow height for light work; 3) 15 to 40 cm below

elbow height for heavy work (Kroemer and Grandjean, 1997). Konz and Johnson (2000)

provided slightly different recommendations for the optimum work surface height: 1) 5

cm below the elbow or slightly below heart level for manipulative hand-arm work; 2)

about 15 to 20 cm below the elbow, with the lower arm at about 45°, for non-

manipulative work. Elbow height is recognized as a general reference for the work

surface height in seated work as well.

Most recommendations for work surface height seem to be applicable to general

work tables. However, the recommendations may not be appropriate for certain jobs or

tasks. A number of researchers have shown work surface heights for specific tasks that do

not fit the above recommendations, even for tasks that are quite widely performed: 1) for

manual materials handling, the optimum height was at the knuckle with the arm vertical

(Konz and Johnson, 2000); 2) for driving screws on a vertical surface with an air-

powered pistol-shaped screwdriver, the subjects rated the lowest perceived exertion or

comfort scale at 114 cm of a work height (Ulin et al., 1990) which is 7.5 cm above the

average elbow height of a general population (106.5 cm); 3) butchers preferred a table

height of 17 to 22 cm below the elbow with a tilted surface of 5 to 10° (Magnusson and

Ortengren, 1987). The optimum work height for non-manipulative work, compared to

'that for manipulative hand-arm work' described earlier, is not known (Konz and Johnson,

2000).

Work surface height is a concern for lab workers who conduct pipette task at different workstations such as lab workbench, safety cabinet/hood, or ontop of analyzing systems. Lab workbenches are most likely at fixed heights and have been designed based on general guidelines in which the workbench height is broadly recommended, depending on type of work (NIEHS, 2001): 1) above elbow height for precision work; 2) just below elbow height for light work; and 3) 10-15 cm below elbow height for heavy work. However, it is frequently observed that pipette users ignore or do not use the recommended guideline of work surface height/workstation. It may be the reason that they can not find appropriate recommendations for pipetting or they have difficulty performing the pipette task for some reason. In fact, the guidelines do not specifically specify workbench heights for pipette work nor is the tool size (the length of a pipette) likely taken into account for in the recommendations although the general rule is that hand should be at elbow height. The hand with a pipette is often located much higher than the elbow level during pipetting. This results in severe wrist deviation and/or shoulder abduction. The work surface height could be lowered to improve wrist and shoulder posture. In a sitting position, it is much more difficult, if not impossible, to meet the recommendations due to either the length of the pipette or the limited space between workbench height and knee height. Muscle activity and posture can be problematic if the pipette task is performed even at the recommended heights for a long period of time. There is also concern that lowering the work surface height may adversely affect neck posture since the pipette-tip is located precisely for taking in and discharging the liquid, and the end of the pipette-tip frequently requires visual attention.

In relation to pipette work, it has been reported that UE muscle activity and/or posture are affected, depending on conditions such as the forceful demand of the pipette operation (Fredriksson, 1995), the design of the pipette (Asundi et al., 2005; Lee and Jiang, 1999), the pipette task (Asundi et al., 2005; Lee and Jiang, 1999), and the arm support type (Feng et al., 1997). However, there is still a lack of information on the effect of work environment factors on muscle activity and posture during pipetting, even though the work surface height has a major impact on job performance and musculoskeletal problems (Kroemer and Grandjean, 1997). Based on review of literature to date, no study has examined how the work surface height affects UE muscle activity, posture, and discomfort or pipetting.

Because the workstation/tool configuration (i.e., human-pipette-work surface height interface) is unique for pipetting, it is of importance to understand how the muscle activity or posture is affected by work environment factors such as work surface height in pipette work. This study examined the effect of work surface height on UE muscle activity, wrist and neck posture, and discomfort at multiple body locations during a laboratory simulated pipette task. In addition, the study was to recommend a guide of work surface height for pipette work.

B. METHODS

1. Subjects

Ten subjects were selected for this study from students, staff members, and faculty at the University of Massachusetts Lowell (UML). The subjects, whose ages ranged from 21 to 49, were all right-hand dominant without musculoskeletal problems or injuries within the past 12 months and had at least six months of experience in pipette use (Table 14). Each subject was interviewed (Appendix E) and agreed to an informed consent form (Appendix F) which was approved by the Institutional Review Board at UML. The subjects, based on the interview results, worked at workstations that the mean height of the work surface was 89.1cm (75 – 102) and the work surface height was not adjustable. Five of the 10 subjects performed pipette work at least 80% of the time in a standing position while the rest worked at least 60% in a sitting position.

2. Experimental setup

Field observations

Pipette tasks being performed by hospital lab workers were often observed during an exposure assessment effort made by UML researchers at a hospital in Massachusetts in 2003 and 2004. A variety of information was obtained using observation, interview, and direct measurement in the hospital laboratories. The information included work surface height, type of pipette, and location of test materials (e.g., rack with vials or tips)

and was used to help design this experimental setup.

Workstation

An experimental workstation was set up using a table, a chair, and test materials (Figure 8). The table top was rectangular (120 cm x 48 cm x 2 cm) and the vertical height was manually adjusted using knobs from 16 cm to 115 cm in infinite increments. A plunger-operated pipette (length: 25.5 cm; fixed volume: 250 ul; VWR brand, USA) was used, and the length with the tip attached was 32.5 cm. Two 20 ml vials, partially filled with water, were placed in a vial rack where the vials were a distance of 27.5 cm apart. A pipette tip rack with a number of tips and a tip waste box was placed on the right side of the vial rack. The location of the racks and the tip waste box was identical for all subjects. The materials were assumed to be typical of those utilized in a general laboratory. The chair had lumbar support and arm rests which could not be adjusted but the height of the seat pan was adjustable for each subject.

Pipette task

Water was horizontally transferred from the left vial to the right on the workstation. The left vial was filled with 15 ml water and 5 ml sand. The sand was included in order to add an element of precision to the task. If the pipette was allowed to touch the sand, the resulting transfer was invalid and had to be repeated. A single fundamental cycle was performed: 1) move to the tip rack from the initial position; 2) insert a tip on the pipette; 3) move to one vial; 4) fill the pipette with water; 5) move to the other vial; 6) discharge water; 7) move to the tip waste box; 8) eject the tip; and 9) return to the initial position.

The fundamental pipetting cycle was repeated continuously 10 times per task cycle. Each task cycle was carried out independently at each of the 6 different experimental heights.

3. Experimental design

The independent variable was work surface height relative to elbow height (6 levels). The dependent variables were muscle activity, wrist posture, neck flexion, and discomfort at 6 body locations. A randomized complete block design was used for the independent variable. In this design, each of the work surface heights was used as a treatment, and subject was used as a block. Repeated measures were obtained on the independent variable with each subject participating in all conditions of the experiment.

Work surface height

Six work surface heights were used in this study (Figure 9). A vertical level (A) was determined as the level of the end point of pipette-tip held vertically in each subject's hand while the subject stands with the upper right arm held close to the side of body; the elbow flexed at 90°; and the forearm and wrist straight, without deviation, in a neutral rotation position. The level was the vertical distance between the floor and the table surface and was defined as a vertical reference level at which the subject's wrist angle became zero. Two vertical levels were determined as levels decreased (B) and increased (C) by 5% of the subject's stature from the reference level (A). It was assumed that the three vertical levels were available for statures ranging from the 5th percentile of US

female civilian stature to the 95th percentile of US male civilian stature (Chaffin et al., 1999).

Once these 3 vertical levels were determined, three work surface heights relative to elbow height were defined, respectively, as the distance from the reference level (A) to each level in standing position: 1) A to B (WSH_{lowest}); 2) A to A (WSH_{lower}); and A to C (WSH_{low}). In order to determine the other three work surface heights, the subject was asked to sit at the original 3 vertical levels and then another vertical reference level (D) was determined as the level for sitting position in the same neutral UE posture as taken in the standing position. Thus, each of the other three work surface heights relative to elbow height could be defined as the distance from the reference level (D) to each of the three previously determined levels in sitting position: 4) D to B (WSH_{high}); 5) D to A (WSH_{higher}); and D to C ($WSH_{highest}$). The latter 3 work surface heights were assumed to be all higher relative to elbow height than the former 3 work surface heights.

For the standing position, each subject stood in front of the experimental workstation on both feet with the entire leg approximately vertical. The sitting position was one in which each subject's ischial tuberosities were resting on the chair with both knees flexed at 90° and feet placed flat on the floor. In that position, the thighs were horizontal and the lower legs were vertical. The distance between table and body was determined by the subjects. Each subject was asked to keep the same distance as well as the same seated height during the experiment.

4. Measurement

Electromyography (EMG) and electrogoniometry were used to measure muscle activity and wrist posture, respectively. These measurements were taken simultaneously and measurement signals were transmitted to a personal computer through analog-to-digital computer interface hardware. A signal connector (BNC-16SE, ComputerBoards, Inc., USA) and a data acquisition board (PCI-DAS 1200, Measurement Computing Corporation, USA) constituted the interface hardware in which analog-digital (A/D) conversion was performed at a 60 Hz sampling frequency. The digital signals were recorded by a data logging software (Labtech Notebook pro, Ver. 12.1, Laboratory Technologies Corporation, USA). Video graphic recordings were used to measure neck posture.

EMG

EMG signals were obtained using disposable surface electrodes which were circular Ag/AgCl electrodes (Blue sensor, Medicotest A/S, Olstykke, Denmark; an active diameter of 0.8 cm and an inter-electrode distance of 2.1 cm). The electrodes were placed in the direction of muscle fibers on the subject's right arm after standard skin preparation (NIOSH, 1992). The muscles to be examined were flexor pollicis longus (FPL), extensor pollicis brevis (EPB), anterior deltoid (AD), and lateral deltoid (LD). A ground electrode was applied over the lateral epicondyle. The positions of the electrodes over each muscle were (Kendall et al., 1993; Feng et al., 1997): 1) FPL: the anterior surface of the forearm about one-fourth of the distance from the radial styloid to the medial epicondyle; 2) EPB:

the posterior surface of the forearm about one-fourth of the distance from the radial styloid to the lateral epicondyle; 3) AD: the anterior surface of the shoulder, 5 cm below the edge of the acromion; and 4) LD: the lateral surface of the shoulder, 5 cm below the edge of the acromion.

The EMG signals of each muscle were amplified and converted into root mean square (RMS) signals. The signals were transmitted to a multi-channel preamplifier, and then an EMG amplifier /RMS converter (Measurement Systems Inc., USA) which was connected to the computer interface hardware. The EMG amplifier was adjustable for different gain levels and the RMS converter had a 55 ms time-constant. The four muscles were recognized as those that were primarily associated with the thumb or the shoulder activity (Kendall et al., 1993; Pansky, 1984). The muscles have the following functions (Kendall et al., 1993): 1) the FPL flexes the interphalengeal joint of the thumb while the EPB extends the metacarpophalangeal joint of the thumb; 2) the AD flexes and medially rotates the shoulder joint while the LD abducts the joint. Previous studies of pipetting have also examined the FPL (Asundi et al., 2005); EPB (Lee and Jiang, 1999; Asundi et al., 2005); AD (Feng et al., 1997); and LD (Lee and Jiang, 1999; Feng et al., 1997). It was assumed that EMG signals for those muscles would reflect the muscle demand required during the pipette task.

For EMG signal normalization (see below), signals of each muscle were obtained both during muscle resting and isometric maximum voluntary contraction (MVC). The resting signals were recorded in a position of the UE while the subjects sat with the right limb relaxed: the arm was rested on the right thigh, and the thumb and other fingers were naturally positioned. The MVC signals were recorded while manual resistance was

applied to each muscle as suggested by Kendall et al. (1993): 1) For the FPL muscle, the interphalangeal joint of the thumb was flexed, with maximum exertion, against pressure placed on the palmar surface of the distal phalanx in the direction of extension by the experimenter; 2) For the EPB muscle, the metacarpophalangeal joint of the thumb was extended against pressure placed on the dorsal surface of the proximal phalanx in the direction of flexion; 3) For the AD muscle, the shoulder was slightly abducted and flexed with the humerus in slight lateral rotation to increase the effect of gravity on the anterior muscle, and then pressure was placed on the anteromedial surface of the arm in the direction of adduction and slight extension; and 4) For the LD muscle, the shoulder was abducted, without rotation but the elbow flexed, against pressure placed on the lateral surface of the distal end of the humerus.

Prior to the MVC tests, the subjects were instructed how to perform these contractions. They were informed to conduct the same level of exertion against pressure placed on a muscle. Thus they were required to keep the exertion level towards the original direction even though the pressure, if any, would be stopped suddenly. This approach was intended to make it possible to collect more reliably the actual maximum voluntary electrical activity of the muscle.

Electrogoniometry

Wrist angles were measured in two planes using a biaxial flexible wire electrogoniometer (XM65, Penny & Giles Biometrics Ltd., UK). Each wrist angle was defined as angular displacement of the hand relative to the forearm in the flexion/extension (F/E) and radial/ulnar deviation (R/U) planes, respectively (Figure 10).

The electrogoniometer was attached on the dorsal surface of the hand-wrist-forearm in-line: the telescopic distal endblock of the goniometer was placed over the third metacarpal of the hand while the wrist was flexed fully, and the fixed proximal endblock was mounted on the surface of the wrist-forearm. The measurement element spring between the two endblocks was straightened along the hand-wrist-forearm when the hand-wrist-forearm was linearly positioned.

The electrogoniometer was connected to a goniometer amplifier (Angle Display Unit, Penny & Giles Biometrics Ltd., UK) which was connected to the computer interface hardware. The goniometer amplifier was zeroed for each wrist plane (F/E and R/U) with a neutral position of the UE: while the subjects stand with the upper arm held close to the side of body; the elbow flexed at 90°; the forearm-wrist-hand are straight, without deviation, in a neutral rotation position; and the thumb and other fingers were naturally positioned. The system was precalibrated with a linear relationship between joint angle and output voltage as shown in equation (1):

$$\text{Joint angle (degrees)} = 90 \times \text{output (volts)} - 225 \tag{1}$$

Video technique for neck posture

Neck postures were captured using two digital video cameras (Sony, DCR-TRV230 and DCR-TRV11, Japan): the former was placed on the right side of the subject for capturing sagittal view (neck flexion/extension) while the latter placed on the rear side of that subject for capturing coronal views (neck lateral bending or twisting). The camcorders were each at a distance of about 290 cm from the subject, and the heights of

both camcorder lenses were adjusted to capture all target body parts along the 6 different

conditions. The horizontal distance and vertical location of each camera were the same

for all subjects.

In order to analyze the neck posture data, two software packages were used: MGI

VideoWave (MGI Software Corp., Version 4.0, Canada) and Windows Movie Maker

(Microsoft, USA), which were installed on a personal computer (PC). The MGI

VideoWave software was used to record the video images onto the PC hard disk. The

Windows Movie Maker software was used for reviewing each captured video file

(moving and still images) on the PC monitor.

To insure consistent quality of the data, video recording and analyses were

performed by a single researcher with experience from other studies (Park, 2002; Park et

al., 2003). The camcorder operation followed the manufacturer's manual.

Subjective ratings

In order to examine the subjects' perception of muscle or posture stress during the

pipette task, discomfort was rated for the pipette task by the subjects. A 100mm visual

analog scale (VAS) with two anchors was used for the thumb, wrist, elbow, shoulder,

neck, and whole body (Figure 11 and Appendix E): 0 for "No discomfort" and 100 for

"Extreme discomfort." Prior to the experiment, the subjects were instructed on the use of

the discomfort scale. At the end of each of the 6 tests, the subjects were asked to draw a

vertical line at a location on the scale which indicated how they would feel performing

the pipette task at the particular experimental condition for 8 hours per day.

5. Experiment procedures

Prior to the experiment, anthropometric data were measured and experimental workstation levels (vertical levels A, B, and C) for work surface heights were determined (Table 14 and Figure 9). Elbow height in sitting was defined as the vertical distance from the floor to the olecranon of the elbow when the subject sat erect, with the feet resting on the floor so that the knees were bent at right angles, the upper arm hanging at the side, and the forearm extended horizontally (Eastman Kodak Company, 1983). Elbow height in standing was defined as the vertical distance from the floor to the olecranon of the elbow when the subject stood in the position that was used for the vertical reference level.

Surface electrodes and the electrogoniometer were attached to the right arm and then connected to the multi-channel preamplifier and the goniometer amplifier, respectively. These amplifiers were attached over the right shoulder of the subject. The subject had time to get used to the workstation, different work surface heights, and the pipette task. In order for use in EMG signal normalization, the EMG signals were collected for 5 s at both resting and MVC conditions. Three trials, separated by at least 1 min, were taken for each condition (as recommended by Mathiassen et al., 1995).

In the experiment, the procedure was blocked on subject and the order of the 6 work surface heights was randomly determined. For first 4 subjects, data were collected based on an earlier version of the study design in which there were two independent variables: work surface height (3 levels) and body position (stand and sitting). The randomization procedure was blocked on body position for the first 4 subjects.

The subject initiated and ended each test on a vocal cue from the experimenter.

Each subject conducted a total of 60 pipetting cycles (6 work surface heights x 10 cycles).

Neck postures were recorded during the 6 tests using two video cameras. The camcorders

were switched on right before the first test and switched off at the end of the last one.

Discomfort was recorded on each VAS at the end of each test. A rest period of 2 min was

provided to the subject between tests to avoid the cumulative effect of local muscle

fatigue. At the end of the experiment, the subjects were asked several questions regarding

their preferences for work surface height and the reasons for their preferences (Appendix

E).

Over the experiment period, data acquisition status for each muscle and wrist

posture was monitored simultaneously on the personal computer monitor. The electrical

activity of a selected muscle was monitored concurrently through an oscilloscope. Prior

to the experiment, the validity of the system was tested: 1) for muscle activity, a level of

force was visually ensured by applying a known level of force which was generated on a

validated system (hand dynamometer and force monitor); 2) for wrist posture, the

measured wrist angle was visually confirmed when the electrogoniometer was positioned

to a known angle; and 3) two video cameras and the personal computer were

synchronized for time. Each subject completed all experimental procedures in a 2-hour

session.

6. Data management

Overall, Table 15 showed the number of measurement measures which were used

in the data analyses for each of 13 dependent variables: muscle activity (4 muscles), wrist

angle (2 wrist planes), neck flexion (1 angle) and discomfort (6 body parts). The total

measurement number for each of muscle activity or wrist angle variable across 10

subjects was 304,252 in which the measurement numbers varied across work surface

heights. The total measurement number, for neck flexion and each of discomfort

variables across subjects, was 180 and 60, respectively.

EMG signal normalization

The EMG signals were normalized in order to make comparisons possible between

different muscles and subjects. The task EMG signals were normalized using equation (2)

which was previously described by Marras and Lavender (1991):

$$EMG_n (\%) = \frac{EMG_{task} - EMG_{rest}}{EMG_{max} - EMG_{rest}} \times 100 \qquad (2)$$

where EMG_n (% of MVC, i.e., %MVC) was the normalized electromyographic activity;

EMG_{task} was the actual electromyographic activity of a specific muscle during simulated

pipetting; EMG_{rest} was the activity obtained when the muscle was resting; and EMG_{max}

was the maximal activity of the muscle during MVC.

Prior to normalization, the raw EMG data (resting, MVC, and task EMG signals)

were visually examined to determine the beginning and end of each trial. A moving

average window of 1 s was used to smooth the EMG data. The smoothed resting signals

were averaged to calculate the 'EMG_rest.' Using the three sets of the smoothed MVC

signals, a maximum signal was captured over the 5 s in each set, and then the highest

value among the three maximum signals was chosen as the 'EMG$_{max}$' (i.e., the

normalization reference value) for each subject. The smoothed task signals (i.e., the

'EMG$_{task}$' data) were individually normalized with equation (2).

Once the normalized EMG activity levels (i.e., the "EMG$_n$" data) were obtained,

the mean of muscle activity levels was determined for each trial (for each work surface

height for each subject) and stored for future data analyses.

Wrist angle

Raw electrogoniometer output data were visually examined and cleaned at the

same time that the raw task EMG data were managed. Using the output data, the mean of

wrist angles was determined for each work surface height for each subject.

Neck angle

Continuous data for neck angle could be collected through detailed analysis of

videotape. Video recordings were visually reviewed on the liquid crystal display panel of

each camcorder and examined for various aspects (e.g., data quality or feasibility of angle

measurement) in a laboratory. It was determined that the video recordings of neck posture

taken from the rear of the subject could be dropped from the data analysis since it was

neither possible to measure neck lateral bending angles taken during a larger flexion

posture nor did there appear to be variations in neck lateral bending between tests during

pipetting.

Neck flexion angle was determined when each subject's neck was bent forward in

the sagittal plane, as the angle between a vertical line and a line perpendicular to a line

between the ear (tragus) and eye (Figure 12). For an angle which was generated from that

vertical line when the subject's neck was bent backward in the sagittal view, the negative

neck flexion or neck extension was determined.

In order to measure the neck angle, the video recordings were captured, using the

MGI VideoWave software, from a video camera to the PC through a cable and stored for

each test (10 repeated pipetting cycles). With the Windows Movie Maker software, each

captured video file of the 10 repeated pipetting cycles was inspected and then three cycles

were randomly determined from the 10 pipetting cycles during inspection on the PC

monitor. One still image was independently taken for each of the three cycles which were

determined for each test. In order to minimize measurement error potential, each picture

was taken at one specific point of each pipetting cycle, and the specific point was same

for all measurements across subjects. The angle of neck flexion was measured using a

protractor at each picture on the PC flat monitor. The mean of the three neck flexion

replicates was determined for each test, and measured neck angle data were stored for

future data analyses.

Discomfort scale

Discomfort scales were measured using a ruler on the 100mm visual scale to the

nearest millimeter for coding. The measured discomfort rating values were stored for the

data analyses.

7. Data analyses

Thirteen dependent variable values were obtained for data analyses: muscle activity (4 muscles), wrist posture (2 wrist plane angles), neck flexion (1 angle), and discomfort (6 body parts). The dependent variables of muscle activity, wrist posture, and neck flexion were determined as the mean for each work surface height for each subject.

The mean values of muscle activity and neck flexion were used to calculate the mean and standard deviation for all subjects. The mean wrist angle values were used to compute the mean for all subjects. Two maximum wrist angles were calculated for all subjects in each plane (Buchholz et al., 2000): 1) maximum radial deviation and maximum ulnar deviation in the radial/ulnar deviation plane; 2) maximum flexion and maximum extension in the flexion/extension plane. The discomfort rating values were used to calculate the mean and standard deviation for each work surface height for across all subjects.

It was hypothesized that each dependent variable would be differently affected by the 6 work surface heights. The randomized block analysis of variance (ANOVA) model was used to test whether there was significant difference in each of dependent variable measures among the 6 work surface heights across 10 subjects. For each of the dependent variables shown to be of significance in ANOVA, a multiple pair-wise comparisons test (Tukey-Kramer method) was performed, in post-hoc analysis, to evaluate whether there was a significant difference between sets of the 6 work surface heights.

In an effort to further explore the effect of work surface height on each of the dependent variables, extensive regression analyses were performed. The experimental

workstation levels and anthropometric data were used for quantifying the independent

variable (work surface height) using equation (3):

$$WSH\,(\%) = \frac{EWL - RL}{Stature\ of\ the\ subject} \times 100 \tag{3}$$

where WSH (%) was the work surface height estimate determined relative to elbow

height; EWL was the level of experimental workstation (Table 14); and RL was the

reference level at either standing or sitting position (A or D in Figure 9). Each reference

level was the location of the pipette-tip at the neutral UE position. The pipette-tip

location was calculated using the subject's anthropometric data by subtracting the actual

pipette-tip length (i.e., the whole pipette-tip length below the pipette handle component)

from the stand/sit elbow height. The length of the pipette handle was used as 8.2 cm

which was the hand breadth for 50th percentile in 50/50 male/female U.S. general

population (Eastman Kodak Company, 1983).

A regression model (i.e., proc glm) was used to estimate the regression coefficients

of the quantified work surface height across 10 subjects. The subject variable was treated

as a random effect in the model. It was assumed that there was no interaction between

two variables such as Subject (block) and Work surface height (treatment). The goodness

of fit was examined for each of the dependent variables.

Spearman correlation coefficients were calculated to examine associations between

discomfort and corresponding direct-measured estimates (muscle activity and posture) for

the same body part.

Statistical significance was defined as $p \leq 0.05$. Data analysis was conducted using SAS 9.1 (SAS Institute Inc., 2003).

C. RESULTS

A total of 60 outcome measures were obtained for each dependent variable from the 10 subjects. The subjects were primarily female and ranged in age from 21 to 49 (Table 14).

1. Muscle activity

The means of mean muscle activity levels varied, depending on muscle: 14%MVC to 21%MVC for flexor pollicis longus; 11%MVC to 21%MVC for extensor pollicis brevis; 9%MVC to 42%MVC for anterior deltoid; and 6%MVC to 32%MVC for lateral deltoid (Table 16 and Figure 13). Across the 4 muscles, the overall highest muscle activity was 42%MVC for anterior deltoid when the pipetting was performed at the work surface height of $WSH_{highest}$, followed by 39%MVC and 35%MVC of the same muscle at WSH_{higher} and WSH_{high}, respectively.

The mean values for each muscle were very significantly different among 6 work surface heights. For anterior and lateral deltoid muscles, the highest mean of muscle activity levels was at $WSH_{highest}$ and the muscle activity levels increased when the work surface heights were increased. However, for flexor pollicis longus and extensor pollicis brevis, the highest mean was at WSH_{lowest} and the muscle activity levels increased when the work surface heights were decreased. There were significant differences, within each of the 4 muscles, in muscle activities between sets of work surface heights.

2. Wrist posture

The mean angles for the R/U deviation plane varied between 8.5° (ulnar) and -9.1° (radial) while those for the F/E plane varied between -28.3° and -33.4° (extension) (Table 17 and Figure 14). The largest mean wrist angle was at flexion/extention plane when the pipetting was conducted at the work surface height of WSH_{lowest}. The radial/ulnar deviation posture was very significantly different across 6 work surface heights and also there was significant difference between sets of work surface heights. However, the flexion/extension posture was neither different across 6 work surface heights nor were there differences, within that wrist plane, between any sets of the 6 work surface heights. When the work surface heights were increased, the angles of the F/E plane decreased towards the neutral wrist angle while the R/U plane angles were mixed.

3. Neck posture

The means of neck flexion means were 1.5° to 29.8° (Table 18 and Figure 15). The neck flexion was very significantly different across 6 work surface heights and there were significant differences between sets of work surface heights. Neck flexion angles increased when the work surface heights were decreased.

4. Discomfort

The means of discomfort scales varied, depending on body part: 16mm to 25mm for the thumb; 14mm to 29mm for the wrist; 16mm to 54mm for the elbow; 16mm to 67mm for the shoulder; 20mm to 49mm for the neck; and 18mm to 41mm for the whole body (Table 19 and Figure 16). The highest discomfort was 67mm on the shoulder at the work surface height of $WSH_{highest}$, followed by 54mm on the elbow at $WSH_{highest}$, and 49mm on the neck at WSH_{lowest}. The elbow, shoulder, and whole body discomfort scales differed across 6 work surface heights. On these body parts, there were also significant differences between sets of work surface heights (Table 19) such that the middle heights were more comfortable than either extreme.

5. Subjective preference of work surface height

With respect to the preference of work surface height, WSH_{lower} was preferred by 4 out of 10 subjects, followed by WSH_{higher} (3), WSH_{high} (2), and $WSH_{highest}$ (1). The most common reasons for the preference were comfort, less strain on UE, and/or visual requirement.

When asked about the influence of work surface height on visual requirement during lab simulated pipetting, seven subjects responded 'strongly', two responded 'moderately', and one responded 'extremely.'

6. Effect of quantified work surface height

Each of 6 work surface heights was quantified for each subject in order to use in the regression analysis (Table 20). The mean value of each work surface height for all subjects was -5% (WSH_{lowest}), 0% (WSH_{lower}), 5% (WSH_{low}), 18% (WSH_{high}), 23% (WSH_{higher}), and 28% ($WSH_{highest}$), respectively.

Using the quantified work surface height data, the effect of the work surface height variable was significant for 10 out of 13 dependent variables across 10 subjects and corresponding resultant coefficients ranged from 0.53 to 0.90 (Table 21). The highest parameter estimate of the work surface height variable was 1.31 for shoulder discomfort ($R^2 = 0.57$), followed by 1.1 for anterior deltoid ($R^2 = 0.90$), 1.0 for elbow discomfort ($R^2 = 0.53$), 0.84 for lateral deltoid ($R^2 = 0.86$) and -0.82 for neck flexion ($R^2 = 0.82$).

7. Correlation between discomfort and direct-measured exposure

Spearman correlation coefficients between discomfort and corresponding direct-measured exposure measures were obtained among selected combinations of dependent variables (Table 22). The highest correlation coefficient was 0.56 between the shoulder discomfort and anterior deltoid muscle activity level, followed by 0.51 between the shoulder discomfort and lateral deltoid activity level, 0.30 between wrist discomfort and flexion/extension angle, and 0.27 between wrist discomfort and radial/ulnar deviation angle. These coefficients were significant across the 6 work surface heights and subjects.

The correlation coefficients for other combinations were 0.15 or less and were not statistically significant.

D. DISCUSSION

1. Findings and implications

The effect of work surface height on muscle activity, posture, and discomfort was evaluated during a laboratory simulated pipette task. Muscle activity, posture and discomfort were very significantly different across 6 work surface heights for each of four muscles, wrist radial/ulnar deviation, neck flexion, and elbow, shoulder, and whole body discomfort.

Notably, biomechanical stresses and discomfort levels at the shoulder were markedly higher, biomechanical stresses at the neck became lower, when work surface heights were increased and the activities of the thumb muscles were lower (Table 16).

The shoulder was required to be flexed or abducted, and the elbow was also required to be extended or flexed. Often, the shoulder was alternatively exerted in either static or dynamic fashion to perform the pipette task during the experiment. The extended static posture might cause fatigue in the shoulder; thus blood demand might be high but blood circulation in the static posture low (NIOSH, 1996).

Different recommendations have been suggested for limiting a worker's muscle activity. In a prolonged or repetitive exertion task (e.g., pipette task), one study recommended that the muscle activity should be less than 30% of MVC (Kroemer, 1989) and another recommended that it should be less than 25% of MVC with a sufficient rest period (Rohmert, 1973). In this study, several muscle activity mean values of anterior deltoid and lateral deltoid exceeded or were close to the recommendations when the

pipetting was performed at the higher work surface heights. The findings indicate that there are likely higher exposure risks for MSDs or injuries at the shoulder when the height of work surface is increased. In this study, the work surface was always too high in the sitting position. In the field, it was more often observed as too high in the sitting position rather than standing. On the other hand, the levels of muscle activity became lower in both the thumb flexor and extensor muscles when the height of work surface was increased, indicating that the muscle fatigue of the thumb muscles would become higher when the work surface height is getting lower during pipetting. The study results implied that the thumb muscles might have had somewhat higher exposure to forceful exertions when the heights of work surface were decreased.

UE postures varied during pipetting, depending on various conditions including work surface height/workstation design, body position, anthropometric characteristics, and type of pipette. The postures of the hand and/or wrist frequently altered. The wrist radial/ulnar deviation angles in this study varied significantly during pipetting among 6 work surface heights, and significant difference was present between two sets of work surface heights (two lowest heights and the rest of heights). The wrist flexion/extension plane angles did not vary across work surface heights during pipetting. The wrist extension mean values did not exceed one recommendation (45°) documented in the literature (Armstrong et al., 1982) but did exceed another (15°) at all heights (McAtamney and Corlett, 1993; Hignett and McAtammney, 2000). The study results indicate that work surface height can more significantly affect the wrist posture exposure in the radial/ulnar deviation plane rather than in the flexion/extension plane during pipette work.

Neck flexion angles were very significantly different among the 6 work surface heights during pipetting. The results appeared to reflect suitably the visual requirements of the simulated pipetting task, indicating that there are likely higher exposure risks for MSDs or injuries at the neck when the work surface heights are too low. In fact, the neck flexion, among the dependent variables of this study, was best explained by work surface height. Several means of neck angles exceeded or were close to the recommended levels suggested in the literature: 20° of flexion or extension (Kilbom et al., 1986; McAtamney and Corlett, 1993); 30° of flexion or lateral bending (Buchholz et al., 1996 and 1998).

Discomfort ratings were affected by work surface height for some body parts. For the elbow, shoulder, and whole body, the rating differences were very significant among the 6 work surface heights while the differences were not significant for the rest of the body parts. The levels of discomfort increased proportionally with the increased work surface heights for the elbow and shoulder but not for the whole body, indicating that the discomfort for the whole body might have a range of variations in rating scores. It was noticeable that discomfort mean scales were commonly lowest at the work surface height of WSH_{lower} over all the body parts except the neck.

When the patterns of discomfort levels were compared for the body part of the thumb or neck, the patterns were different from those of muscle activity and posture levels. This finding is consistent with the fact that worker's rating may not correspond with objective measurements (Armstrong et al., 1989). On the other hand, such patterns were markedly similar for the shoulder and wrist. In particular, the Spearman correlation coefficients were significant only for the shoulder and wrist. These findings may be used to explain the correlation between discomfort and direct-measured exposures.

Among the 6 work surface heights, WSH_{lower} was the most preferred (by 40% of

the subjects). The three work surface heights employed in the sitting position were more

preferred than that (WSH_{lower}) in standing (60% vs. 40% of the subjects): 1) the

preferences for WSH_{lower} were primarily related to UE strain or comfort issue; 2) for

WSH_{high} were comfort, visual requirement, and UE strain; 3) for WSH_{higher} were visual

requirement or comfort; and 4) for $WSH_{highest}$ were visual requirement and comfort.

These findings imply that the preference of work surface height during simulated

pipetting might have been affected by other than biomechanical and discomfort factors,

and that one of such factors would be visual requirement in that 80% of the subjects

responded as 'strongly' or 'extremely' with regard to the effect of work surface height on

visual requirements.

Prior to this study, it was expected but not known how significant the effect of

work surface height would be during pipetting since there was a lack of experimental

evidence. Since the heights of lab workbenches were most likely set based on general

guidelines which did not provide information for specific work (e.g., pipetting), it was

observed that pipette users frequently worked at inappropriate work surface heights. In a

sense, the height of lab pipette workbench should be considered as a level which is to be

lowered by the length of a pipette from the elbow height.

It was noticeable that, as the height of the work surface was increased, the activity

levels of the shoulder muscles increased but the neck flexion levels were decreased. For

such biomechanical exposures, difference levels were found not only across the 6 work

surface heights but also between more stratified sets of the work surface heights. The

subjective preference data fairly reflected the importance of the work surface height. In

the extensive examination of regression work, it was shown that the quantified work surface height had significant effects on 77% of the dependent variables regardless of the subjects and that the regression model had higher power of explanation for biomechanical stresses rather than for discomfort in general. The parameter estimate of the work surface height appeared to reflect the earlier results, i.e., the pattern of each dependent variable outcome levels among the 6 work surface heights, as shown in Tables 16 through 19 and Figures 13 through 16. The parameter estimates were positive for shoulder muscle activity, wrist posture, wrist discomfort, elbow discomfort and shoulder discomfort whereas they were negative for thumb muscle activity, neck flexion posture and neck flexion discomfort. In particular, the regression results supported the findings that the work surface height effects were more significant on the dependent variables of the shoulder and neck than other dependent variables with higher parameter estimates, significance levels and resultant coefficients. Furthermore, correlation between discomfort and corresponding direct-measured exposure measures was meaningfully high for the shoulder.

Work surface height is a concern. A more specific guide or recommendation of work surface height is required for pipette workstations. The findings imply that the work surface height should be determined on the basis of the biomechanical stresses and discomfort levels. In this study, the shoulder was most affected by the work surface height and the neck was second most affected. The wrist in R/U deviation plane was remarkably influenced while the thumb muscle activity and thumb discomfort were fairly affected by the work surface height in general. In determination of the work surface height, there is a trade-off that when the work surface heights are increased, the levels of

biomechanical stress proportionally increase for some dependent variables (the shoulder) but decrease for other dependent variables (the neck and thumb). The R/U deviation wrist angle and discomfort levels are lowest at the work surface heights of WSH$_{low}$ and WSH$_{lower}$, respectively.

Noticeably, the biomechanical stress and discomfort levels of the shoulder exceed the general recommendations at the higher work surface heights, implying that the work surface heights of pipette workstation should not be designed for a sitting position. With respect to the findings in this study, since it is recognized that the exposure levels at the shoulder and neck should be primarily controlled, the height of work surface should be determined as a level where muscle and posture stress levels at the shoulder and neck can be lowered, at least, below the recommended muscle activity and neck posture levels. In this context, the work surface height for pipetting would be best when the hand is slightly above the elbow height.

2. Implication of experimental design

Pipette users often conduct pipette tasks at a laboratory workstation such as a workbench or safety cabinet/hood. They frequently perform manipulative activities with different body positions (sitting, standing, or reaching to an upper shelf). The current study was designed to reflect the effect of work surface heights on muscle activity, posture, and discomfort with a holistic point of view. The effect of work surface height during pipetting was evaluated in conjunction with workstation/tool configuration. That is, the study design took into account the workstation-pipette-human interface as well as

dimensions of individual elements (e.g., work surface height, pipette, and subject) and also considered a potential interaction between work surface height and subject under the configuration.

The interval distance between two work surface heights was determined as 5% of the subject's stature. The interval distance might be suitable for the study subjects (one or more of three vertical levels were unavailable for 95th percentile or taller person when 10% of the subject's stature was used at the given workstation). With that interval distance, the experimental workstation would not allow more than 3 work surface heights for the standing position. However, the 6 work surface heights could be obtained when they were determined relative to elbow height (not possible when determined relative to the lab floor). In fact, the three vertical levels of the experimental workstation were determined in the stand position since at least one of the three levels would be too low to use for pipetting in stand position if they were determined in the sitting position with the pipette-tip held in the subject's hand (see Figure 9). In addition, a reference vertical level for the sitting position was too low for leg clearance due to the pipette-tip length.

It was recognized that the results of the study would provide more useful information about the effect of work surface heights on muscle activity, posture, and discomfort when 6 work surface heights rather than 3 work surface heights were employed in this study design. This experimental design could produce extensive information on certain work surface height effects which could be generated in higher extreme levels of the standing body position. Thus, the 6 work surface heights were finally determined at an early stage of the current study although first several subjects were used in an earlier version of the experimental design (experimental condition and

randomization were identical except a block variable, i.e., body position, which was used for those subjects).

A component of visual requirements was added in the study design by putting sand into a vial. The visual requirements might have been enhanced due to the sand since each subject was asked not to touch the sand during pipetting. Such design would affect the subjects who performed the pipette task with multiple functions. The multiple functions might include holding the pipette handle with four fingers, pressing the plunger with the thumb, repeating 10 pipetting cycles, effort to avoid touching the sand in the vial, and hearing the vocal cues of the experimenter. That is, the subject was required to do multiple functions such as psychophysical components (information processing and sensing) as well as biomechanical components (forceful exertion and repetition), indicating that such design might have made the experimental conditions closer towards the field conditions.

In an experimental design of pipette work, understanding the human-pipette-workstation interface would improve the understanding of how biomechanical and psychophysical exposures could be influenced by a work environmental factor such as work surface height. For the issue of experimental design for a study in which a hand tool is used at a workstation, it would be suggested to design the experiment in conjunction with the workstation/tool configuration in order to produce more suitable information.

3. Strengths and limitations of this study

Strengths

The experimental evidence consisted of quantitative data with respect to work

surface height. Through a well-designed experiment, a direct measurement method can provide more specific evidence that can not be obtained from other methods (observation or workers' self-report). This study could provide accurate evidence on biomechanical exposures (forceful and postural stresses) at 6 work surface heights during pipetting. Also this study could obtain psychophysical measure outcome data (discomfort rating) which could provide information of psychological exposure (e.g., fatigue or pain) as well as physical exposure (e.g., muscle strain) (Gescheider, 1985) although only very short term outcome data might not be predictive of clinical disorders or other long term outcomes.

In a randomized block design, each block can form a more homogeneous experimental unit on which a factor can be compared more accurately (Montgomery, 1997). The experimental data did not have any major problems with assumptions of variance equality or linearity in an extensive analysis of residuals. The randomization of subjects and test orders in the experiment minimized interaction between work surface height (treatment) and subject (block).

Study limitations

Although this study was finally designed for one independent variable with 6 levels, the earlier version of the study design was used for the first 4 subjects. In the earlier study design, the order of the three work surface heights was determined randomly within a block (body position) which was also determined randomly in the experiment. Therefore, the earlier randomization procedure used in the experiment might have affected the results by increasing interaction between two independent variables (work surface height and body position).

There is a potential cross talk since EMG and electrogoniometry were employed in this study. In order to minimize this problem, muscle selection and electrode attachment were determined based on the literature (NIOSH, 1992; Kendall et al., 1993; Feng et al., 1997; Buchholz et al., 2002). Muscle tests were performed to confirm electrode placement and to examine cross-talk. For example, the EMG electrode locations were palpated manually to maximize the signals from the thumb flexor/extensor and minimize the signals from the other muscles such as wrist flexors/extensors (Buchholz et al., 2002). The electrogoniometer system was zeroed and operated based on the manufacturer's manual in order to eliminate the sources of error due to crosstalk. However, since the crosstalk might have increased with increased forearm rotation (Hansson et al., 1996; Buchholz and Wellman, 1997), errors in the wrist measurements were potentially generated from crosstalk of the goniometer.

This study used 10 university personnel who might not be representative of the general pipette user population. The experiment was not performed at a field workplace where a wider variety of sources of variability would exist. Since a single factor of work surface height was examined in this study while other factors (e.g., pipette type, and location of test materials) were controlled, the results are limited to those factors used here, and thus it cannot be determined how much the true results might be underestimated or overestimated in the laboratory conditions. Moreover, although it has reported that there are work organizational and psychosocial factors (e.g., work content, work pacing, or level of autonomy) in pipette work (Bjorksten et al., 1994; David and Buckle, 1997), the effects of these factors were not addressed in this study.

E. CONCLUSIONS

To evaluate the effect of work surface height on muscle activity, posture, and discomfort in a pipette task, a laboratory experiment was conducted with 10 university students, staff members, and faculty as subjects. The experiment design consisted of one independent variable and thirteen dependent variables. The independent variable was work surface height (6 levels) and the dependent variables were: upper extremity (UE) muscle activity (percent of maximum voluntary capacity [%MVC] for 4 muscles), wrist posture (angle for 2 planes), neck flexion (1 angle), and UE discomfort (rating for 6 body parts). Subjects were otherwise free to position their hands and arms as they wished during lab simulated pipetting.

The following study results were obtained:

- The activity levels of thumb and shoulder muscles were significantly different across the 6 work surface heights (p<0.0005)

- The posture levels of radial/ulnar deviation and neck flexion were significantly different among the 6 work surface heights (p<0.0001)

- The discomfort scales on the elbow, shoulder, and whole body were significantly different across the 6 work surface heights (p<0.005)

- Differences in each of the above biomechanical and discomfort variables between sets of the 6 work surface heights were significantly high (p<0.05).

UE muscle activity, wrist posture, neck flexion, and discomfort were affected by the 6 work surface heights during simulated pipetting. The work surface height

significantly influenced 9 out of 13 dependent variables during simulated pipetting. When the work surface heights were increased, muscle strain and discomfort levels were markedly higher at the shoulder whereas neck flexion levels became lower.

The study suggests that work surface height can influence UE muscle activity, posture and discomfort in general laboratories, and that the biomechanical exposure at the shoulder and neck should be primarily controlled in order to prevent the risk of MSDs or injuries in pipette work.

F. RECOMMENDATIONS

It has been often documented that muscle activity is associated with posture in a specific joint. In particular, since the wrist flexor/extensor muscle strength (Kattel et al., 1996; Hallbeck and McMullin, 1993), the peak lateral pinch strength (Mital and Kumar, 1998) and the maximum power grip strength (Pryce, 1980) are reduced when the wrist is flexed, extended or deviated, the association between muscle activity and posture in the wrist may be varied at different work surface heights during pipetting. Further study would provide useful information on how the association between muscle activity and posture in a joint would be influenced by factors including work surface height during pipetting.

The study findings can be practically utilized for pipette users who want to understand exposure to biomechanical risk factors during pipette work at various work surface heights. The findings can be applied to understanding the workstation/tool configuration as well as individual equipment or system.

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Table 14

Demographic, anthropometric, and workstation level information of subjects in this study

Subject	Sex	Age (year)	Work year (year)	Pipetting duration per test (s)	Weight (kg)	Stature (cm)*	Shoe heel (cm)	Stand elbow height (cm)	Sit elbow height (cm)	Level of experimental workstation (cm)		
										B†	A†	C†
A	M	25	4	92.2	79.3	189	2.5	116.3	64.0	84.6	94.0	103.5
B	F	21	3	79.3	54.4	163	4.0	98.3	60.5	67.8	76.0	84.2
C	M	36	5	122.1	76.0	176	3.0	106.8	64.0	75.7	84.5	93.3
D	F	34	10	93.2	75.0	164	7.5	103.0	64.0	71.3	79.5	87.7
E	F	25	4	66.0	58.0	165	2.5	104.5	67.0	71.2	79.5	87.8
F	F	43	2	77.3	131.4	165	3.0	106.0	68.5	76.2	84.5	92.8
G	F	21	4	65.1	67.5	169	4.5	103.5	66.5	73.0	81.5	90.0
H	F	45	20	85.5	72.5	162	2.0	98.5	61.0	67.4	75.5	83.6
I	F	25	4	88.6	61.2	167	6.0	104.5	69.5	73.1	81.5	89.9
J	F	49	4	75.8	92.4	168	3.0	104.0	64.5	73.1	81.5	89.9
Mean	-	32.4	5.8	84.5	76.8	168.8	3.8	104.5	65.0	73.3	81.8	90.3
SD		10.5	5.4	16.5	22.2	8.1	1.8	5.0	2.9	4.9	5.2	5.6

*: This study used stature in which the width of shoe heel was included.

†: Level A, which was determined relative to the floor (see Figure 9), was used as the vertical reference level in standing position. Two other vertical levels were determined by ±5% of the subject's stature from the reference level (A).

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Table 15

Number of measurement measures used in the data analyses by work surface height for each of dependent variables such as muscle activity (4 muscles*), wrist angle (2 wrist planes), neck flexion (1 angle) and discomfort (6 body parts).

Work surface height	Muscle activity (%MVC)	Wrist angle (degree)	Neck flexion (degree)	Discomfort (mm)
WSH$_{lowest}$	51,660	51,660	30	10
WSH$_{lower}$	52,363	52,363	30	10
WSH$_{low}$	50,672	50,672	30	10
WSH$_{high}$	49,385	49,385	30	10
WSH$_{higher}$	50,167	50,167	30	10
WSH$_{highest}$	50,005	50,005	30	10
Total	304,252	304,252	180	60

* : Each muscle, for example, had a total of 51,660 %MVC which were used in the data analyses for the work surface height of WSH$_{lowest}$ across 10 subjects.

Table 16

Mean and standard deviation (SD) of mean activity levels (%MVC) during

simulated pipetting by muscle (n= 10 subjects)

Muscle	Work surface Height	Muscle activity level (%MVC)		P†
		Mean	SD	
Flexor pollicis longus	WSH$_{lowest}$	21**	10.6	0.0003
	WSH$_{lower}$	18	10.2	
	WSH$_{low}$	18	9.2	
	WSH$_{high}$	17	9.4	
	WSH$_{higher}$	15*	6.4	
	WSH$_{highest}$	14*	7.0	
Extensor pollicis brevis	WSH$_{lowest}$	21**	13.3	<0.0001
	WSH$_{lower}$	17	10.8	
	WSH$_{low}$	14*	6.5	
	WSH$_{high}$	13*	6.5	
	WSH$_{higher}$	11*	4.9	
	WSH$_{highest}$	12*	6.0	
Anterior deltoid	WSH$_{lowest}$	9*	2.9	<0.0001
	WSH$_{lower}$	12*	4.1	
	WSH$_{low}$	15*	5.3	
	WSH$_{high}$	35**	12.1	
	WSH$_{higher}$	39	12.0	
	WSH$_{highest}$	42***	13.1	
Lateral deltoid	WSH$_{lowest}$	6*	3.2	<0.0001
	WSH$_{lower}$	7*	4.7	
	WSH$_{low}$	8*	4.4	
	WSH$_{high}$	23**	11.3	
	WSH$_{higher}$	27	13.5	
	WSH$_{highest}$	32***	14.4	

† Significance for each muscle across 6 work surface heights in the
  ANOVA test.
*, **, and *** indicate the different sets of work surface heights, within each
  muscle, in the Tukey-Kramer test.

Table 17

Mean, maximum radial/ulnar deviation (Max rad or uln) and maximum flexion/extension (Max flex or ext)

of mean wrist angles in two planes among work surface heights during simulated pipetting (n= 10 subjects)

Work surface height	Radial/ ulnar deviation§ (degrees)				Flexion/ extension§ (degrees)			
	Mean	Max rad	Max uln	P†	Mean	Max ext	Max flex	p†
WSH$_{lowest}$	-9.1*	-16.7	7.0	<0.0001	-33.4	-69.9	-	0.32
WSH$_{lower}$	-4.5*	-10.8	5.9		-32.8	-60.3	-	
WSH$_{low}$	2.7**	-4.4	13.8		-32.9	-51.7	-	
WSH$_{high}$	6.1**	-5.3	16.6		-31.6	-46.9	-	
WSH$_{higher}$	8.3**	-3.9	14.0		-29.6	-39.5	-	
WSH$_{highest}$	8.5**	-4.5	18.7		-28.3	-41.1	-	

§: The negative sign indicates radial deviation and extension.

†: Significance for each wrist plane angle across 6 work surface heights in the ANOVA test.

* and ** indicates the different sets of work surface heights, within the wrist plane angle, in the Tukey-Kramer test.

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Table 18

Mean and standard deviation (SD) of subject mean neck flexion angles by

work surface height during simulated pipetting (n= 10 subjects)

Work surface Height	Neck flexion (degrees)		p†
	Mean	SD	
WSH_{lowest}	30***	6.2	<0.0001
WSH_{lower}	26***	4.6	
WSH_{low}	24***	4.7	
WSH_{high}	13**	5.8	
WSH_{higher}	9**	6.8	
$WSH_{highest}$	2*	6.2	

† Significance for the neck flexion across 6 work surface heights
   in the ANOVA test.
*, **, and *** indicate the different sets of work surface heights,
   within the neck flexion, in the Tukey-Kramer test.

Table 19
Mean and standard deviation (SD) of discomfort scales during simulated pipetting by body part (n= 10 subjects)

Body part	Work surface Height	Discomfort scale† (mm)		p†
		Mean	SD	
Thumb	WSH$_{lowest}$	19.4	24.9	0.44
	WSH$_{lower}$	15.6	22.1	
	WSH$_{low}$	17.4	25.0	
	WSH$_{high}$	22.0	22.6	
	WSH$_{higher}$	21.5	20.3	
	WSH$_{highest}$	25.0	22.3	
Wrist	WSH$_{lowest}$	19.4	19.8	0.20
	WSH$_{lower}$	13.8	16.8	
	WSH$_{low}$	17.3	20.6	
	WSH$_{high}$	23.8	18.2	
	WSH$_{higher}$	25.4	18.1	
	WSH$_{highest}$	28.8	21.7	
Elbow	WSH$_{lowest}$	22.1*	23.8	0.0004
	WSH$_{lower}$	15.6*	17.6	
	WSH$_{low}$	19.1*	17.3	
	WSH$_{high}$	33.7	26.2	
	WSH$_{higher}$	37.7	27.0	
	WSH$_{highest}$	54.1**	21.5	
Shoulder	WSH$_{lowest}$	23.2*	26.1	<0.0001
	WSH$_{lower}$	15.8*	17.4	
	WSH$_{low}$	24.2*	22.5	
	WSH$_{high}$	42.5	24.7	
	WSH$_{higher}$	43.1	26.9	
	WSH$_{highest}$	66.9*	30.1	
Neck	WSH$_{lowest}$	48.9	33.8	0.11
	WSH$_{lower}$	22.2	31.3	
	WSH$_{low}$	32.9	29.2	
	WSH$_{high}$	24.2	24.0	
	WSH$_{higher}$	20.3	24.9	
	WSH$_{highest}$	35.0	34.1	
Whole body	WSH$_{lowest}$	41.0**	26.8	0.0049
	WSH$_{lower}$	18.3*	18.4	
	WSH$_{low}$	21.2	15.8	
	WSH$_{high}$	20.1	18.3	
	WSH$_{higher}$	22.4	19.2	
	WSH$_{highest}$	38.6	19.3	

* Significance for each body part across 6 work surface heights in the ANOVA test.
* and ** indicate the different sets of work surface heights, within each body part, in the Tukey-Kramer test.

Table 20

Work surface heights for the regression analysis

Subject	Work surface height (%)*					
	WSH_{lowest}†	WSH_{lower}	WSH_{low}	WSH_{high}	WSH_{higher}	$WSH_{highest}$
A	-5	0	5	23	28	33
B	-5	0	5	18	23	28
C	-5	0	5	19	24	29
D	-5	0	5	18	23	28
E	-5	0	5	16	21	26
F	-5	0	5	18	23	28
G	-5	0	5	17	22	27
H	-5	0	5	18	23	28
I	-5	0	5	16	21	26
J	-5	0	5	18	23	28
Mean	-5	0	5	18	23	28
SD	0	0	0	2	2	2

*: The work surface height was estimated, as a distance from each reference level at either body position, relative to elbow height of each subject.

†: The negative sign denotes the direction against WSH_{low} from the reference level (Figure 9).

Table 21

Regression coefficients for the effect of work surface height on each dependent variable

in the regression model across 10 subjects

Dependent variable	Work surface height		R^2
	Parameter estimate	p-value	
Flexor pollicis longus muscle activity	-0.17	<0.0001	0.89
Extensor pollicis brevis muscle activity	-0.25	<0.0001	0.77
Anterior deltoid muscle activity	1.10	<0.0001	0.90
Lateral deltoid muscle activity	0.84	<0.0001	0.86
Wrist radial/ulnar deviation	0.50	<0.0001	0.75
Wrist flexion/extension	0.14	0.0227	0.77
Neck flexion	-0.82	<0.0001	0.82
Thumb discomfort	0.22	0.0569	0.81
Wrist discomfort	0.37	0.0149	0.57
Elbow discomfort	1.0	<0.0001	0.53
Shoulder discomfort	1.31	<0.0001	0.57
Neck discomfort	-0.32	0.2296	0.41
Whole body discomfort	0.0007	0.9971	0.37

Table 22

Spearman correlation between discomfort and corresponding direct-measured exposure

measures for 10 subjects and 6 work surface heights (n= 60 measures)

Discomfort	Direct-measured exposure	Spearman correlation	
		Coefficient	p-value
Thumb	%MVC of flexor pollicis longus	0.15	0.2548
Thumb	%MVC of extensor pollicis brevis	0.03	0.8060
Wrist	Wrist angle of radial/ulnar deviation	0.27	0.0375
Wrist	Wrist angle of flexion/extension	0.30	0.0192
Shoulder	%MVC of anterior deltoid	0.56	<0.0001
Shoulder	%MVC of lateral deltoid	0.51	<0.0001
Neck	Neck flexion†	0.07	0.6119

† Measures which were obtained using video techniques.
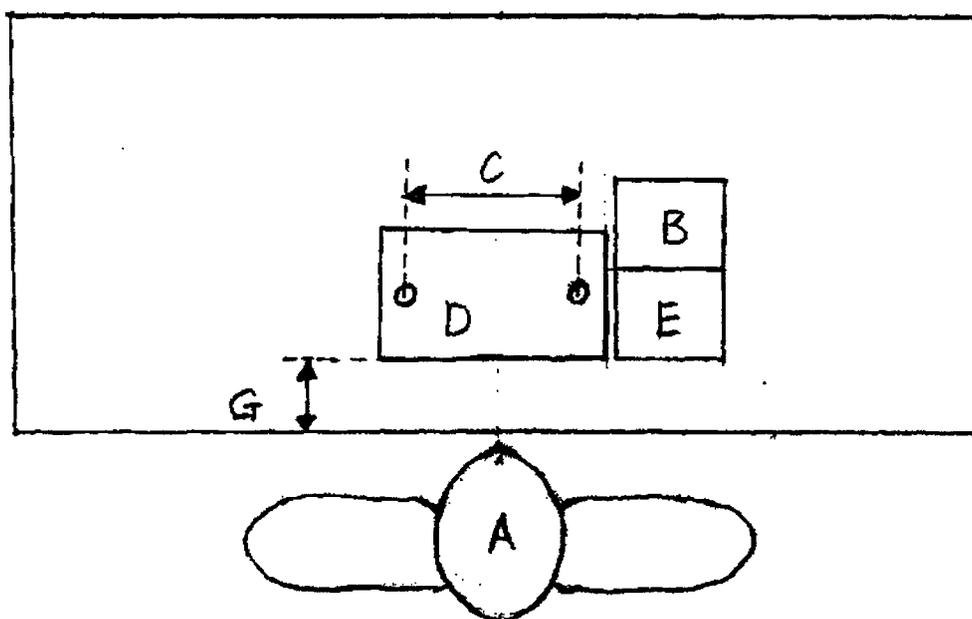
Figure 8. Workstation layout for laboratory simulated pipette task. A: Subject; B: Tip

rack; C: Distance of two vials (27.5cm); D: Vial rack; E: Tip-waste box; and G: Distance

of test materials from the table edge (10cm).
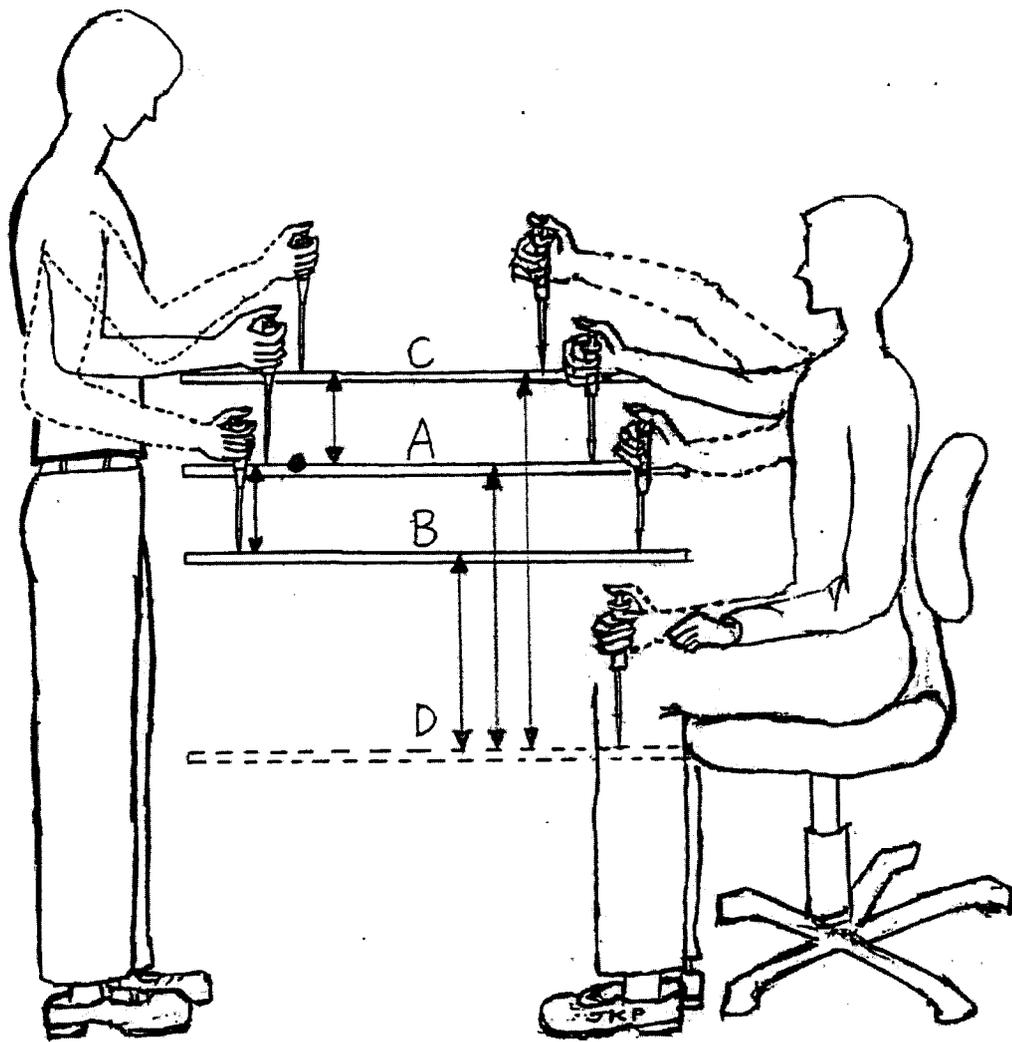
Figure 9. Six work surface heights used in this study. Vertical level (A), a reference level, was determined in standing position. Two vertical levels (B and C) were determined from the reference level (A). Each of three work surface heights relative to elbow height was defined as the distance from the reference level (A): 1) A to B (WSH_{lowest}); 2) A to A (WSH_{lower}); and A to C (WSH_{low}). For the other three work surface heights, another vertical reference level (D) was determined in sitting position. Each of the other three work surface heights relative to elbow height was defined as the distance from the reference level (D) to each of the three previously determined levels: 4) D to B (WSH_{high}); 5) D to A (WSH_{higher}); and 6) D to C ($WSH_{highest}$).
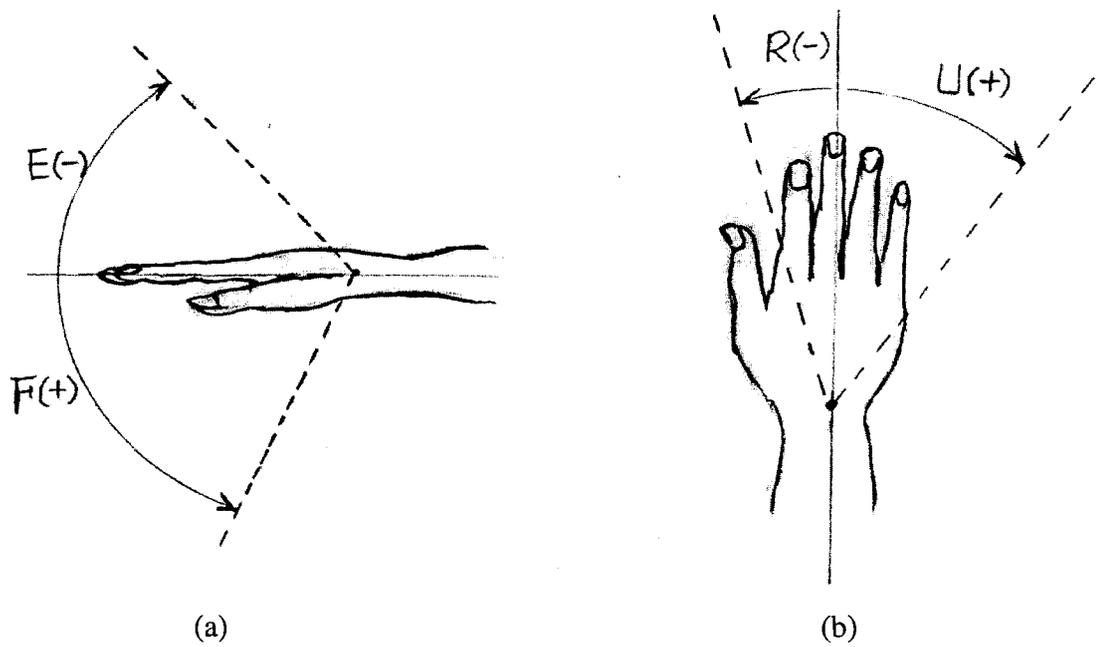
Figure 10. Wrist angle in flexion/extension (F/E) and radial/ulnar deviation (R/U) planes.

```
No discomfort                                          Extreme discomfort
Test __           0                                                100mm
      Thumb      |-----------------------------------------------------------|
      Wrist      |-----------------------------------------------------------|
      Elbow      |-----------------------------------------------------------|
      Shoulder   |-----------------------------------------------------------|
      Neck       |-----------------------------------------------------------|
      Whole body |-----------------------------------------------------------|
```

Figure 11. A set of 100mm long visual analog scales used for discomfort rating on

different body parts.

Figure 12. Neck flexion angle (A) during pipetting.
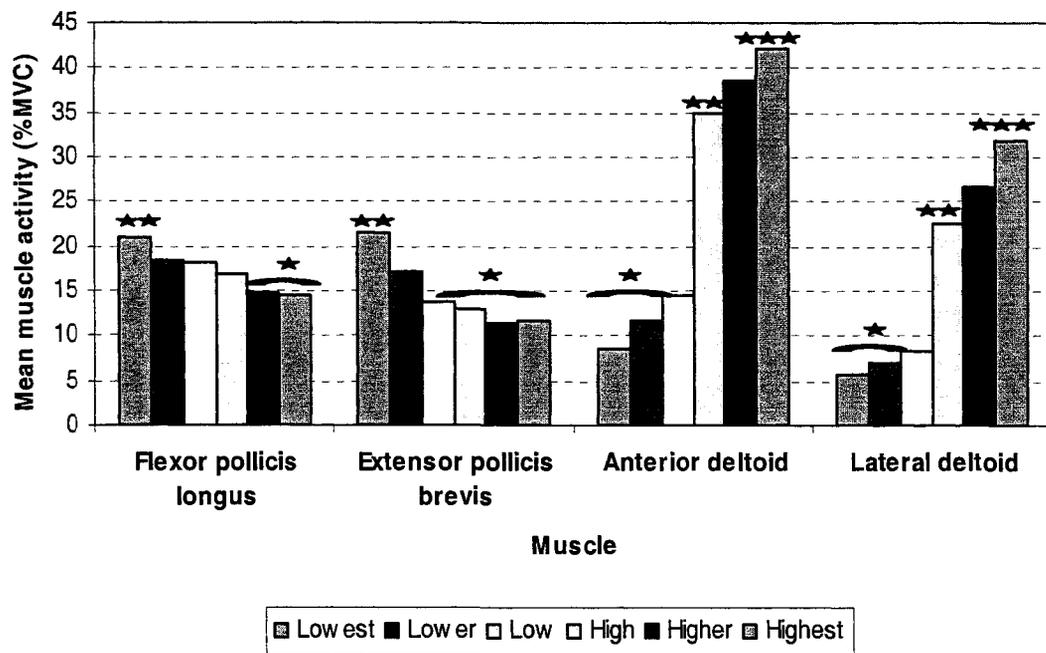
Figure 13. Means of mean activity levels (%MVC) during simulated pipetting by muscle.

★, ★★ and ★★★ indicate sets of work surface heights (Tukey-Kramer test,
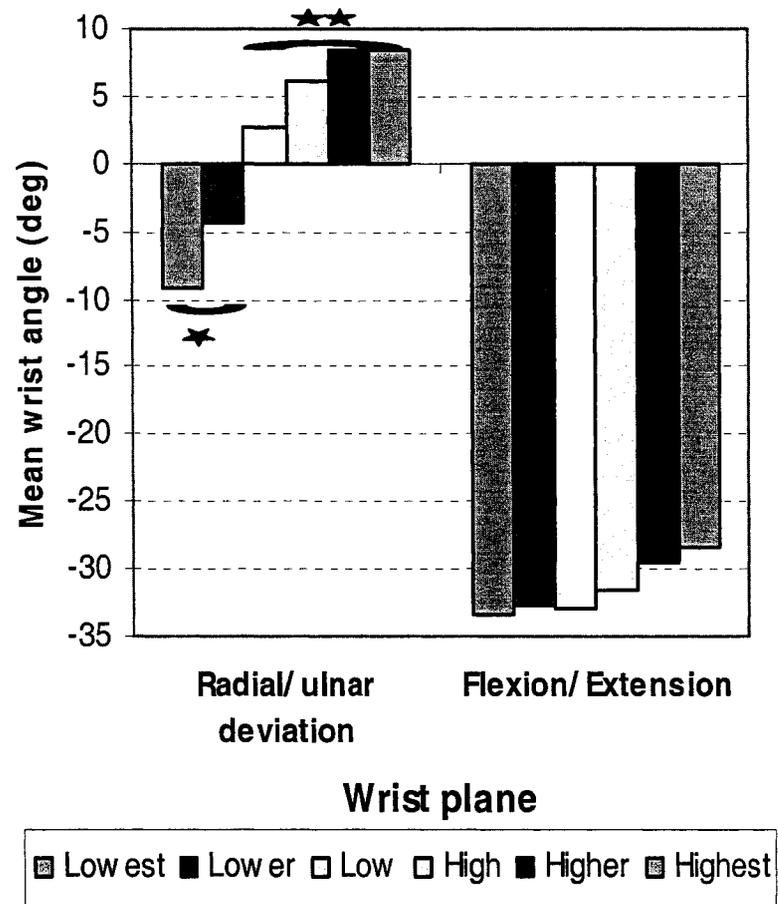
$p < 0.05$) (n= 10 subjects).

Figure 14. Means of mean wrist angles in two wrist planes were shown across work

surface heights. The negative sign indicates radial deviation and extension. ★ and ★★

indicate sets of work surface heights (Tukey-Kramer test, p<0.05) (n= 10 subjects).

Work surface height

| ▦ Low est | ■ Low er | □ Low |
| □ High | ■ Higher | ▦ Highest |
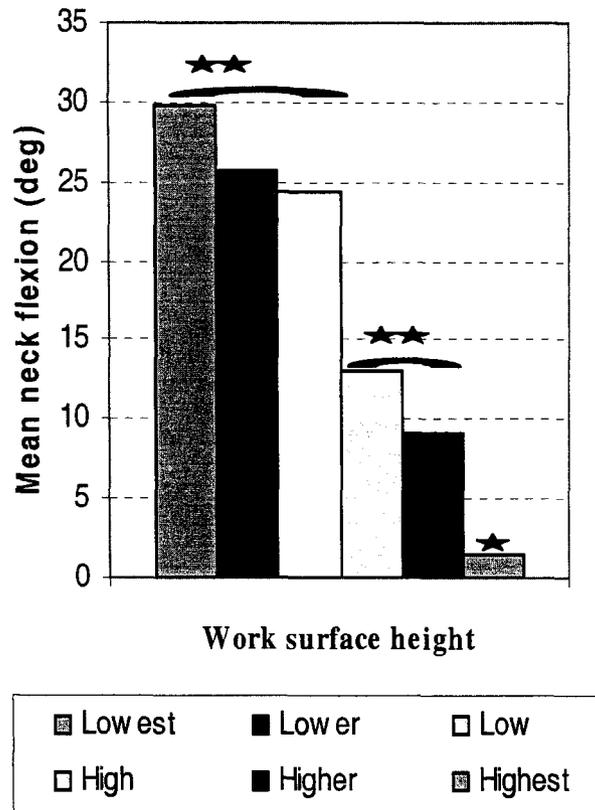
Figure 15. Means of mean neck flexion angles were shown across 6 work surface heights.

★ and ★★ indicate sets of work surface heights (Tukey-Kramer test, p<0.05) (n= 10
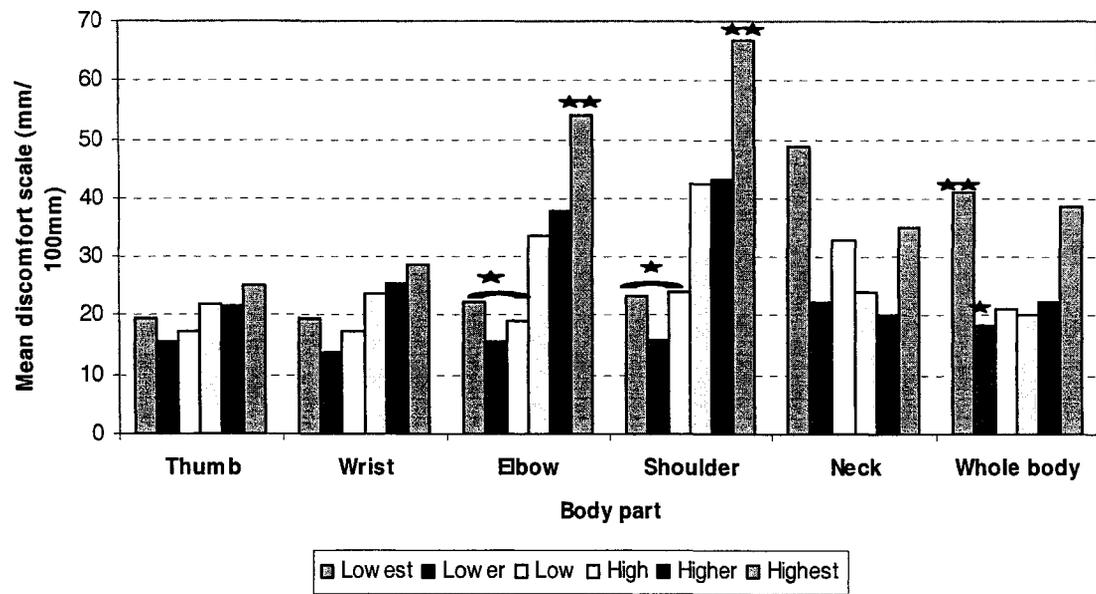
subjects).

Figure 16. Means of discomfort scales were shown across 6 work surface heights by body part. ★ and ★★ indicate sets of work surface heights (Tukey-Kramer test, p<0.05) (n= 10 subjects).

CHAPTER V. CONCLUSIONS

This thesis research has conducted three independent studies to examine exposure to biomechanical risk factors for upper extremity musculoskeletal disorders (UEMSDs) or injuries in hospital laboratories. The three studies are: 1) inter rater reliability assessment of a newly revised PATH method in hospital work; 2) characterization of biomechanical exposure to upper extremity musculoskeletal disorder risk factors in hospital laboratories; and 3) effect of work surface height on muscle activity and posture during simulated pipetting. Various findings were obtained from each of three studies and discussed.

A. INTER RATER RELIABILITY OF A REVISED PATH METHOD

A version of the PATH (Posture, Activity, Tools, and Handling) observational method (Buchholz et al., 1996) was newly revised to characterize upper extremity as well as whole body ergonomic exposures in healthcare industry. The inter-rater reliability (IRR) level of the revised PATH method was good for most of 18 ergonomic risk factors in the hospital work. Also, the revised instrument was tested for more comprehensive set of PATH variables including distal upper extremity (UE) postures, repetitive hand activities, and work conditions (e.g., vibration, hand/forearm contact stress), which were

not included in the previous version of the PATH method. The jobs used for the IRR

examination were all multiple mixed tasks (non-routine jobs).

It is shown that the revised PATH instrument can allow one to describe ergonomic

exposure in hospital settings. On the other hand, since the revised instrument can

characterize ergonomic exposure to hand/forearm MSD risk factors such as hand/forearm

postures, repetitive hand activities, work conditions (e.g., hand/forearm contact stress),

and weight in hands, it is possible to assess ergonomic exposure in hospital hand

intensive jobs such as laboratory technician or clerical assistant.

In this context, the revised PATH method can be reliably applicable to non-routine

jobs such as hospital work, indicating that the revised method has a wider range of

applications to different industries.

B. CHARACTERIZATON OF EXPOSURE TO BIOMECHANICAL RISK FACTORS

Exposure to biomechanical risk factors was characterized using a subset of PATH

observation data which were collected for a larger exposure assessment research study.

The data subset was collected from laboratories of a hospital using the revised PATH

method. Information on laboratory organization and work operations was provided

through a taxonomy. The primary risk factors were non-neutral UE postures and hand

activity level (HAL) ranges (Range 1: 0 to <3.3 of HAL; Range 2: 3.3 to <6.7; and Range

3: 6.7 to 10) (Latko et al., 1997). An exposure frequency was estimated for each of 24

laboratory work shifts.

The results of exposure frequency showed markedly high exposure to postural strain for the distal UE and also showed moderately high level of hand activity in the hospital laboratory work. Thus, biomechanical exposures to non-neutral postures and repetitive hand motion can be significant in hospital laboratories.

Exposure frequency differences were not significant for most non-neutral UE postures and HAL ranges when exposure frequencies were compared with respect to job category, handwork activity, or laboratory type. However, for pinch grip among non-neutral UE postures, it was noticeable that the difference of exposure frequencies was significant between low and high levels of handwork activity.

In the study, the taxonomy could be used to understand features of lab organizations and work process in hospital laboratories. PATH exposure data were used for characterization of biomechanical exposure in lab work. Such exposure should be assessed in relation to specific tasks and equipment design features in order to inform intervention efforts in the clinical laboratories.

C. MUSCLE ACTIVITY AND POSTURE DURING SIMULATED PIPETTING

During simulated pipetting in a laboratory, the effect of work surface height on UE muscle activity, posture, and discomfort was evaluated for 10 university personnel. The activity levels of the shoulder and thumb muscles were very different across the 6 work surface heights as were the postures of wrist radial/ulnar deviation and neck flexion and discomfort of the elbow, shoulder, and whole body. For the above specified measures,

differences in levels of muscle activity, posture, and discomfort were shown to be significant between sets of work surface heights.

Muscle force and posture angle levels were much higher at extreme work surface heights. As work surface heights increased, the levels of muscle activity and discomfort at the shoulder were markedly higher whereas neck flexion angle was lower. These findings were supported by extensive regression analyses and subjective preferences. Biomechanical stress and discomfort levels at the shoulder and neck should be primarily controlled in the reduction or prevention of the exposure risks in pipette work.

A guide of work surface height is required for pipette workstations and the height of work surface should be specified in conjunction with workstation/tool configuration. One or a range of the 6 work surface heights could be referred to in the guide. It is desirable to determine the work surface height as a level in which muscle and posture stress levels at the shoulder and neck can be lowered, at least, below the recommended muscle activity (e.g., percent of maximum voluntary contraction) and neck posture levels. The study results show that the height of work surface for pipetting can be best when the hand is slightly above the elbow height.

This study suggests that upper extremity muscle activity, posture, and discomfort can be influenced by work surface height in pipette work, and that such information can be utilized in ergonomic improvement of laboratory equipment design and layout.

D. SUMMARY AND CONCLUSIONS

The goal of this thesis research was to provide information for reducing or preventing biomechanical exposure to risk factors for MSDs in hospital laboratories. Each of three studies could be summarized as the following conclusions: 1) The revised PATH instrument has an acceptable IRR level and can be applicable in hospital work; 2) Employing the revised PATH method, in combination with a taxonomy, can usefully characterize exposure to non-neutral distal UE posture and hand activity in hospital laboratories; and 3) Exposure to biomechanical stressors can be most significantly affected at the shoulder and neck when the height of work surface is increased or decreased during pipetting.

The three studies had different scopes (e.g., worker, work or organization aspect) or methodological approaches to assess ergonomic exposure (see Figure 2). However, there were common areas (e.g., exposure assessment, biomechanical risk factors for MSDs or hospital laboratories) which allowed each study results to link together with respect to biomechanical exposure in hospital setting. Thus the results of this dissertation can be useful information which provides insight to understand exposure profiles at different points of aspects and then leads to the reduction or prevention of biomechanical exposure risks for MSDs in hospital laboratories.

E. LITERATURE CITED

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APPENDIX A. PHASE PATH template (paper-and-pencil version)

PATH Template v5.72 JKP-JT-JB 05-19-03

Version 5.72 — Body Template (45 secs)

Worker Number:	1	2	3	4	5	6	7	8	9	10	11	12
Not Obs/Not Sure												
Trunk Posture	1	2	3	4	5	6	7	8	9	10	11	12
neutral <20												
mod flex >20 - <45												
severe flex >45												
lat bent/twist flexed												
lat bent/twist neutral												
Not Obs/Not Sure												
Leg Posture	1	2	3	4	5	6	7	8	9	10	11	12
Stand (flex <35)												
Walking/Running												
Sitting												
Kneeling (1 or both)												
Squat (both kn's >80)												
Lunge (1 knee >35)												
Crawl												
Stand on 1 foot												
Not Obs/Not Sure												
Shoulder/Arm Elevation	1	2	3	4	5	6	7	8	9	10	11	12
Both arms <60												
1 arm >60												
2 arms >60												
Not Obs/Not Sure												
Elbow Posture	1	2	3	4	5	6	7	8	9	10	11	12
Neutral (30 - 150)												
Extension (>150)												
Extreme Flexion (<30)												
Not Obs/Not Sure												
Weight in Hands (lbs)	1	2	3	4	5	6	7	8	9	10	11	12
< 10 lbs												
10 - 50 lbs												
50 - 150 lbs												
>150 lbs												
Not Obs/Not Sure												
MMH	1	2	3	4	5	6	7	8	9	10	11	12
No MMH												
1 hand												
2 hands												
Not Obs/Not Sure												
MMH Action	1	2	3	4	5	6	7	8	9	10	11	12
NO MMH												
Carry/Hold												
Push/Pull/Drag												
Lift												
Lower												
Not Obs/Not Sure												
Noise Level	1	2	3	4	5	6	7	8	9	10	11	12
0												
1												
2												
Not Obs/Not Sure												
Vibration	1	2	3	4	5	6	7	8	9	10	11	12
None												
Segmental												
Whole-Body												
Not Obs/Not Sure												

Hand/Forearm Template (30 secs)

Worker Number:	1	2	3	4	5	6	7	8	9	10	11	12
Not Obs/Not Sure												
Neutral / Gross Grasp	1	2	3	4	5	6	7	8	9	10	11	12
No												
Yes												
Not Obs/Not Sure												
Wrist/FA Deviation	1	2	3	4	5	6	7	8	9	10	11	12
No												
Yes												
Not Obs/Not Sure												
Pinch Grip	1	2	3	4	5	6	7	8	9	10	11	12
No												
Yes												
Not Obs/Not Sure												
Keyboarding	1	2	3	4	5	6	7	8	9	10	11	12
No												
Yes												
Not Obs/Not Sure												
H/FA Contact Stress	1	2	3	4	5	6	7	8	9	10	11	12
No												
Yes												
Not Obs/Not Sure												
Vibration	1	2	3	4	5	6	7	8	9	10	11	12
No												
Yes												
Not Obs/Not Sure												
Weight in Hands (lbs)	1	2	3	4	5	6	7	8	9	10	11	12
< 10 lbs												
10 - 50 lbs												
50 - 150 lbs												
>150 lbs												
Not Obs/Not Sure												
Hand Observed	1	2	3	4	5	6	7	8	9	10	11	12
Right												
Left												

Hand Activity Level - observe 15 seconds continuous

	1	2	3	4	5	6	7	8	9	10	11	12
place 0-10 score here												

Hand Activity Level Scale

0	Hands idle most of time, no regular exertions
2	Consistent, conspicuous pauses
4	Slow steady motion, frequent pauses
6	Steady Motion, infrequent pauses
8	Rapid steady motion, no regular pauses
10	Rapid steady motion, difficulty keeping up

:45	B	06:45	B	12:45	B
01:30	H	07:30	H	13:30	H
02:15	B	08:15	B	14:15	B
03:00	H	09:00	H	15:00	H
03:45	B	09:45	B	15:45	B
04:30	H	10:30	H	16:30	H
05:15	B	11:15	B	17:15	B
06:00	H	12:00	H	18:00	H

APPENDIX B. Inter rater reliability for each item in PATH training data

Table B-1

Inter rater reliability for each item in PATH training data. 95% confidence interval (95%

CI) and significance (p-value) are obtained for kappa.

Item	Inter rater reliability (n= 72 observation pairs)			
	% agreement	Kappa		
		Coeff.	95% CI	Classification †
1. Trunk posture	52.3	0.20 **	0.06 ~ 0.34	Poor
2. Leg posture	76.1	0.20 *	-0.05 ~ 0.46	Poor
3. Shoulder/arm elevation ‡	64.7	0.29 **	0.06 ~ 0.52	Poor
4. Elbow posture ‡	60.9	0	-	Poor
5. Weight in hands ‡	97.1	0.48 ***	-0.13 ~ 1.0	Fair to good
6. Manual materials Handling (MMH)	67.2	0.02	-0.02 ~ 0.07	Poor
7. MMH action	71.6	0.03	-0.03 ~ 0.09	Poor
8. Noise level ‡	66.7	0.39 **	0.22 ~ 0.56	Poor
9. Vibration	100	- §	-	-
10. Neutral/ gross grasp	52.9	0.04	-0.23 ~ 0.32	Poor
11. Wrist/ forearm Deviation	52.9	-0.13	-0.38 ~ 0.12	Poor
12. Pinch grip	55.8	0.11	-0.16 ~ 0.37	Poor
13. Keyboarding	87.0	0.48 ***	0.17 ~ 0.78	Fair to good
14. Hand/ forearm contact stress	70.4	-0.15	-0.24 ~ -0.05	Poor
15. Vibration	79.6	0	-	Poor
16. Weight in hands ‡	100	- §	-	-
17. Hand observed	100	1.0 ***	-	Excellent
18. Hand activity level ‡	86.7	¥	-	-

† Classification of kappa/ weighted kappa (Fleiss, 1981): poor agreement beyond chance for <0.4; fair to good agreement beyond chance for 0.4 - 0.75; excellent agreement beyond chance for >0.75.

‡ Ordinal variable for which weighted kappa was calculated.

* p< 0.05;   **: p<0.01;   ***: p<0.001.

§ Undefined (zero in the denominator).

¥ Sample size requirement was not met.

APPENDIX C. Workforce and subjects observed during PATH observation

Table C-1

Entire workforce, weekly average workforce, and observed subjects during PATH

observation

Lab section	Job title	Job code	Workforce	Workforce / wk‡	Subject observed
Lab Chemistry*	Clinical scientist II	2530	6		1 + 1 (†,*)
	Lead clinical scientist	2940	1	6	
	Clinical scientist I	3150	3		1 (*)
	Specimen processing coord	3690	1		
Hematology	Sr. lab supervisor	2390	1		1 (§)
	Clinical scientist II	2530	2	4	
	Lead clinical scientist II	2940	1		1
	Clinical scientist I	3150	3		2
Blood Bank	Lab supervisor	2190	1		
	Clinical scientist II	2530	2	4	
	Donor program clinical tech	2670	2		
	Clinical scientist I	3150	1		1 (†)
Microbiology	Lab supervisor	2190	1		1 (†)
	Clinical scientist I	3150	4	3	1 (†)
Pathology (histology, cytology)	Histology coordinator	2260	1		
	Clinical scientist histology	2490	2		1
	Pathology assistant	3180	2	6	1
	Medical secretary	5430	1		
	Pathology secretary	5870	1		
Administration	Lab services administrative	1600	1		
	Coord lab info systems	2440	1	3	
	Admin asst (N)	5300	1		
Support services	Coord client services	2060	1		
	Lab assistant	3160	24		1 + 1 (*)
	Lab stock technician	3520	1	12	1
	Lead lab assistant	3700	1		1
	Lab data processing clerk	5900	7		1 (†)
Night lab	Lab supervisor	2190	1		
	Clinical scientist II	2530	10	12	1 (†,*)
	Clinical scientist I	3150	4		
Total	20		88	50	18

‡ Weekly workforce was on average 50 (38, 9, and 3 for 1st, 2nd, 3rd shifts, respectively) in 2004.

* Lab chemistry administratively included Specimen processing section where two (2530 and 3150) of Lab chemistry, one (3160) of Support services, and one (2530) of Night lab were observed while they worked on a rotation basis.

† Six out of 18 subjects were observed twice.

§ Senior lab supervisor (2390) was observed in Administration office where she usually worked.

APPENDIX D. Checklists

1. PHASE PATH Cover Sheet

2. PHASE Super Cover Sheet

3. Checklist for hospital laboratory work

PHASE-in Healthcare - *PATH* cover sheet - Version 2.95_JP_06/24/04

Pre-Observation Data

REPEAT VISIT: YES   NO
PDA Used*:   127   093   529
*(See serial number on back of PDA)

1.   **Descriptive data** (Observer)

Date: _____   Facility: _____

Analyst: _____   Department: _____

Observer ID: _____   Area: _____

Observation Start Time: _____   Job Title: _____

Observation End Time: _____

Strong/noticeable odors upon arrival in the work area: **YES / NO**

Comment:_____

House-keeping:	☐ Very Good	☐ Good	☐ Bad	☐ Very Bad
	well controlled storage and cleanliness	neat and orderly; some clutter but generally contained	housekeeping is fair; some clutter on pedestrian traffic routes	dirty and poor storage of materials

2.   **Shift Information**: (Supervisor)

Shift start time: _____

End time: _____

Days per week: _____

Comment:

_____

_____

3.	**Brief Description of time observed (Single or Multiple Tasks) and approximate amount of time spent in identified/major tasks.**

<u>Description</u>   <u>% of Time</u>

_____ _____

_____ _____

_____ _____

_____ _____

4.	**Staffing conditions:**

a) Any understaffing in this shift?		**YES / NO**

   If YES, number of staff missing per total staff scheduled: ------- **(insert ratio)**

b) (1) Missing from same job title as observed?	**YES / NO**

   If NO, from which job title: _____

b) (2) Anyone on restricted duty/light duty from same job title?	**YES/NO**

c)	Any unusual deadlines today?		**YES / NO**

   Comment: _____

   _____

d)	Any broken or missing equipment that will affect the workday?	**YES / NO**

   Comments: _____

5.	**Workers observed:**

Ergo Cat #	Worker Number	Name / Initials [worker code]	Dom. Hand	Sex	Race	Latino Y/N/NK	# of years or months this job	Specific Tasks	A few descriptors: (hair color/style, clothes, height, build, etc.)

Post Observation Data

6. Inter - Worker Homogeneity

Based ONLY on what was observed, and only if more than 1 worker was observed, what was the workers homogeneity:

1	2	3	9
Uniform All workers perform the same tasks	**Intermediate** Some overlap between tasks performed by workers	**Different** Workers perform distinctly different tasks	*Not Obs/Not Sure* Only one worker observed or only one in title or not sure

7. Exit Interview Questions

A. - Were you working under any deadlines during this period?

YES / NO

What deadlines:
a.) _____

_____

b.) _____

_____

c.) _____

_____

Do these deadlines happen often?

YES / NO

Tell me more about _____(one deadline)_____ [nature of deadline]

_____

_____

_____

_____

B. Were there any obstacles to getting your work done on time today?

YES / NO

What was the biggest obstacle?

_____

_____

C. "How does the workload in this department during the summer compare with the workload at other times of the year?"

8.   Observer Assessment: Typical Work Day?   YES / NO

*** *If necessary, indicate different exposures or ratings with individual workers initials.* ***

9.   Visibility:

Difficulties with visibility: Always^4 / Often^3 / Sometimes^2 / Never^1

Specify: _____

_____

10.   Rest/recovery time (During this time period only)
        A. Took formal breaks and meals only:
                        YES / NO   _____ (min)
        B. Took informal breaks (quick sit, friendly chat, etc.):
                        YES / NO   _____ (min)

11.   HIGH Time Pressure: Always^4 / Often^3 / Sometimes^2 / Never^1

Comment: _____

_____

12   Static Posture(s):

Any tasks or activities that contained static postures of long duration?   YES / NO

Specify: _____

_____

_____

13   Body Support:

SEATED or   **STANDING**
If Seated
Without functional backrest or shoulder support: **YES / NO**

Using backrest: **Always⁴ / Often³ / Sometimes² / Never¹**

Using shoulder support: **Always⁴ / Often³ / Sometimes² / Never¹**

If Standing (if present)
   A) *Floor mat:*   *Always⁴ / Often³ / Sometimes² / Never¹*

   B) *Footrest:*   *Always⁴ / Often³ /*
Sometimes² / Never¹

[Note: Items #14 and #15 were removed.]

		Always – 4	*Often - 3*	*Sometimes - 2*	*Never - 1*
16.	*Cold:* *Ambient:*				
	Manual:				
17	**Heat:** Ambient:				
	Manual:				
18.	**Poor IAQ:**				
19.	**Gloves:**				
	Thick and/or Bulky:				
	Thin: Latex:				
	Other:				
20.	**Other PPE:**				
	Specify:				

21. Chem: Hazardous chemicals are used during the shift				
22. Fire Flammable vapors are likely to be formed during task - or open flames are present				
23. Sharps Use of contaminated needles or other sharps required by task.				
24. Cuts Task requires working with or near sharp objects.				
25. STF Slip trip and fall hazards, check if slippery (wet) surface, cluttered floors, or if climbing stairs ladders, stools etc				
26. Hi-Volt Potential contact with high voltage sources during job.				
27. Burn Task(s) performed near hot surfaces				
28. Mach – Tasks performed in the vicinity of exposed moving parts.				

SUPER Cover Sheet

1. Facility _____	2. Analyst _____	3. Job Title _____
4. Job Title Code _____	5. Department _____	6. Dept. Code _____
7. Date(s) of data collection _____		

8. **Information Sources**

    a. Official Information from facility job description:

    b. Discussion with supervisor

    c. Discussion with worker(s)

    d. Informal conversations during walkthrough

    e. Case study team records review

    f. Case study team key informant interviews

    g. Case study team focus groups

    h. Other: _____

9a.   **PATH**: Date of first observation _____;

9b: **PATH**: Date(s) of subsequent observations: _____

10. OPV: Date(s) of psychosocial observations: _____

11. Work Routinization:

1	2	3	4	5
Single Routine Task	Multiple Routine Tasks	Single Variable Task	Multiple Tasks, Mixed	Multiple Variable Tasks (no cycle)

12. Positioning:	☐ Single-task, single activity [1] *(e.g. 1 station, only insert screws)* ☐ Single-task, multiple activities [3] *(e.g. 1 station, operates multiple machines)* ☐ Multiple tasks[2] *(e.g., rotate through stations, perform different tasks throughout day)*

[Note: #13 removed on 03.30.04. Data will be collected separately]

14.Patient Handling	Yes _____ No _____			
15. Patient Care	Yes _____ No _____			
16. Services to Friends, Family Members or Legal Guardians of Patients	Yes _____ No _____			
17. VDU Operation	Yes _____ No _____			

[Note: Questions #18 and #20 were removed 03.30.04. See version 2.2r for details.]

19. Frequency of overtime:

21. Absenteeism common:

22. Contract employees utilized:

23. Responsibility for safety and health of other <u>EMPLOYEES</u>:

N/A 9	Very Limited 1	Limited 2	Average 3	Significant 4	Very Significant 5
	Worker bears little responsibility for safety of others	Worker responsible for safety of others within narrow limits	Worker must maintain periodic vigilance to ensure others are not injured by his/her actions or inattention	Continual care to ensure safety of others; constant vigilance.	Safety of others depends mainly on the corrective actions of worker

24. Responsibility for safety and health of <u>PATIENTS</u>:

N/A 9	Very Limited 1	Limited 2	Average 3	Significant 4	Very Significant 5
	Worker bears little responsibility for safety of patients	Worker responsible for safety of patients within narrow limits	Worker must maintain periodic vigilance to ensure patients are not injured by his/her actions or inattention	Continual care to ensure safety of patients; constant vigilance.	Safety of patients depends mainly on the corrective actions of worker

Field Notes:

Checklist for Hospital Laboratory work

■ General

Date: _____   Observer: _____

Job title: _____ Job code:_____

General information available from existing PATH data: Yes_____ / No_____

Rotation: lab sections _____ and work duration: _____

■ Operation

Lab section	Operation*	Yes/ No
Specimen processing	Pre-sample processing	
	Sample processing	
	Post-sample processing	
	Others	
Lab chemistry	Automated chemistry	
	Manual chemistry	
	Others	
Hematology	Automated hematology	
	Manual hematology	
	Others	
Blood bank	Blood testing (type, cross match, or HIV)	
	Blood bank database review	
	Others	
Microbiology	Automated microbiology	
	Manual microbiology	
	Others	
Pathology (histology or cytology)	Automated tissue preparation	
	Manual sample preparation	
	Others	
Administration	Staffing	
	Planning and budgeting	
	Others	
Lab support services	Phlebotomy	
	Specimen transport	
	Material management and stock	
	Data processing	
	Others	

■ Overall job process and task description observed at work area of the lab section

| |
| |

| Note: |
| - Tasks: Pipetting; Microscopy; Safety cabinet or hood work; Using a microtome; Using a cryostat; Using a flow cytometer; Glove box (anaerobic chamber) work; Using a centrifuge; Using a cell counter; Video display unit work; Others |
| - Handwork activities: work pace, degree of dynamic or static load in conjunction with tasks observed |
| - Ergonomic risk factor: physical/ psychosocial/ organizational factors |
| - Equipment/ tool/ material: model, maker, shape, size, diameter, weight |

■ Workstation dimensions

| |
| |

■ Pipette task

| - Total amount of time spent pipetting during past 12 months (hours/day or week) |
| - Duration spent continuously doing pipetting (min/   ) |
| - Pipette type: Plunger operated (   ) Transfer pipette (   ) |
| _____ (   ) _____ (   ) |
| - Pipette maker, model, size (length and hand width), weight: |
| - Test tubes or bottles: |
| - Worker height and weight: _____ & _____ |

APPENDIX E. Interview questions for simulated pipette task

Interview Questions for simulated pipette task

Date Prepared: June 15, 2005

Project Title: "An evaluation of muscle activity and posture of upper extremity during
simulated pipette work"
Principal Investigator: Jungkeun Park   Co- Researcher(s): Bryan Buchholz

■ General

Department at UML: _____ Status /job title: _____

Experience year of pipette work: _____   Age:_____

Upper extremity musculoskeletal problems within the past 12 months: (Yes___ No___)

■ Questions

1. Which of following three work surface heights would you prefer best?
   1) Down level (   ) 2) Neutral (i.e., Zero-wrist angle) (   ) 3) Up level (   )

2. Which of following six combinations, in consideration of workstation configuration,
   would you prefer best?
   1) WSH_{lowest}: down level at stand (   )
   2) WSH_{lower}: neutral (i.e., zero-wrist angle) at stand (   )
   3) WSH_{low}: up at stand (   )
   4) WSH_{high}: down at sitting (   )
   5) WSH_{higher}: neutral at sitting (   ), and
   6) $WSH_{highest}$: up at sitting (   )

3. How does the work surface height affect the visual requirement of pipetting?
   1) Extremely ( ); 2) Strongly ( ); 3) Moderately ( ); 4) Somewhat ( ); 5) Not at all ( )

4. Is work surface height adjusted for pipetting at your current workbenches (Y/N)?___
   What's the height of the workstation where you most typically work?:_____

5. During pipetting at your workstation, how often do you work in stand_____%;
   sitting_____%; others:_____% on a typical workday basis.

6. Type of pipettes typically used at your lab: _____

■ Test: MVC test

Muscle	Time			Remarks
Muscle rest				Neutral position of upper extremity
FPL				
EPB				
Deltoid, anterior				
Deltoid, lateral				

■ Test: task EMG, wrist angle, and discomfort*

Test No.	Experimental condition	Time (min and s)	Discomfort (mm)
	WSH$_{lowest}$: down level at stand		Thumb:_____ Wrist:_____ Elbow:_____ Shoulder:_____ Neck:_____ Whole body: _____
	WSH$_{lower}$: neutral at stand		Thumb:_____ Wrist:_____ Elbow:_____ Shoulder:_____ Neck:_____ Whole body: _____
	WSH$_{low}$: up at stand		Thumb:_____ Wrist:_____ Elbow:_____ Shoulder:_____ Neck:_____ Whole body: _____
	WSH$_{high}$: down at sitting		Thumb:_____ Wrist:_____ Elbow:_____ Shoulder:_____ Neck:_____ Whole body: _____
	WSH$_{higher}$: neutral at sitting		Thumb:_____ Wrist:_____ Elbow:_____ Shoulder:_____ Neck:_____ Whole body: _____
	WSH$_{highest}$: up at sitting		Thumb:_____ Wrist:_____ Elbow:_____ Shoulder:_____ Neck:_____ Whole body: _____

* Sheets used for drawing a vertical line (see 'How would you rate discomfort?' below)

■ Workstation and anthropometric data

Dimensions	Measurement		
Work surface height with pipette-tip in stand	( ) cm		
Work surface height	(1.) cm (2.) cm (3.) cm	(4.) cm (5.) cm (6.) cm	
Stature (shoe heel included)	( ) + ( )= ( ) cm		
Elbow height (Standing)	( ) cm		
Sitting height	( ) cm		
Elbow height (Sitting)	( ) cm		
Height of seat surface	( ) cm		
Others	Gender: Weight:		

Researcher _____   Date: _____

How would you rate discomfort?

No discomfort   Extreme discomfort

Test 1   0   100mm

Thumb |--|

Wrist |--|

Elbow |--|

Shoulder |--|

Neck |--|

Whole body |--|

Test 2   0   100mm

Thumb |--|

Wrist |--|

Elbow |--|

Shoulder |--|

Neck |--|

Whole body |--|

Test 3   0   100mm

Thumb |--|

Wrist |--|

Elbow |--|

Shoulder |--|

Neck |--|

Whole body |--|

Test 4   0   100mm

Thumb |---|

Wrist |---|

Elbow |---|

Shoulder |---|

Neck |---|

Whole body |---|

Test 5   0   100mm

Thumb |---|

Wrist |---|

Elbow |---|

Shoulder |---|

Neck |---|

Whole body |---|

Test 6   0   100mm

Thumb |---|

Wrist |---|

Elbow |---|

Shoulder |---|

Neck |---|

Whole body |---|

Name: _____   Date: _____

APPENDIX F. Informed consent form

UNIVERSITY OF MASSACHUSETTS LOWELL
Institutional Review Board
Informed Consent Form

Date Prepared: June 15, 2005
Project Title: "An evaluation of muscle activity and posture of upper extremity during
simulated pipette work"
Principal Investigator: Jungkeun Park
Co- Researcher(s): Bryan Buchholz

APPROVED FOR USE BY THE UNIVERSITY OF MASSACHUSETTS LOWELL INSTITUTIONAL
REVIEW BOARD.

_____   _____
Signature of IRB Chairperson   Date of Approval

**This Informed Consent Form is <u>valid for a period not to exceed one year</u> from the Date of Approval
appearing above.**

Purpose
You are being asked to participate in a research study which examines the muscle activity of upper extremity.
The purpose of this experiment is to measure the muscle activity and the wrist angle during types of simulated
pipetting task.

Procedure and Duration
In interview session, the outline of all tests will be introduced and a measurement (e.g., arm length) will be
taken. In test session, electromyography (EMG) will be used to measure the muscle activity while
electrogoniometry will be utilized to measure wrist postures. At the end of each task, subjective ratings for
perceived exertion level will be asked. The expected duration of these tests is approximately 2 hours.

Risks and Discomfort
There is a small risk of electrical shock associated with EMG. However, it is minimal because the system is
designed to minimize the risk. The surface electrode and electrogoniometer are attached on the skin over the
target muscle. That is, they are non-invasive and non-needle sensor. Alcohol pad is used for cleaning skin
without side effects. Any fatigue or discomfort on upper extremity joints would be induced by the simulated
pipetting operation but it would be minimal.

Incentives/Compensation
You will be given a gift card for your participation in this research project. The gift card, equivalent to $20, will
be used at UML bookstores.

Benefits
Subjects will gain knowledge about the level of muscle activity and the range of wrist angle during pipetting
operation, and understand how the pipetting may adversely influence the musculoskeletal system, leading that
they can apply the knowledge to the prevention of UEMSDs in the lab pipette work.

Refusal or Withdrawal of Participation
Participation in this study is strictly voluntary, and your participation or non-participation will not affect other
relationships (e.g., employer, school, etc.). You may discontinue your participation as a human subject in this
research study at any time without penalty or costs of any nature, character and kind.

Academic Year 2004-2005 only

Project Title: "An evaluation of muscle activity and posture of upper extremity during
                 simulated pipette work"

Privacy and Confidentiality
Every precaution shall be taken to protect your privacy and the confidentiality of the records and data pertaining to you in particular and the research project in general, disclosure of which may contribute to identifying you specifically to persons not related to this research project. Video tapes, as supplementary data, will be used to document the simulated pipetting tasks. The tapes will be destroyed no later than three years after the completion of this research project.

Additional Information
If you do not understand any portion of what you are being asked to do or the contents of this form, the Researchers are available to provide a complete explanation. Questions relating to this research project are welcome at any time. Please direct them to Jungkeun Park, the Principal Investigator at UML, or Bryan Buchholz, Ph.D., the Faculty Advisor, at the following addresses/telephone numbers:

Jungkeun Park,	Bryan Buchholz, Ph.D.
Dept. of Work Environment	Dept. of Work Environment
University of Massachusetts Lowell	University of Massachusetts Lowell
One University Ave.,	One University Ave.,
Lowell, MA 01854	Lowell, MA 01854
Home Tel. # 978-453-5319	Campus Tel. # 978-934-3241
Daytime Tel. # 978-934-4378	

_____
Principal Investigator   Date

_____   _____
Co-Researcher(s)   Date   Faculty Advisor (if applicable)   Date
[Every individual listed as a Researcher must sign this form,
and all Researchers must sign on the same page.]

I understand the foreseeable risks and/or discomfort that have been described in this document.

I have read the statements contained herein, have had the opportunity to fully discuss my concerns and questions, and fully understand the nature and character of my involvement in this research program as a participant and the attendant risks and consequences.

_____   _____
Research Participant   Date   Agency Official (if applicable)   Date

A COPY OF THIS INFORMED CONSENT FORM IS TO BE GIVEN TO THE RESEARCH STUDY PARTICIPANT WHO HAS SIGNED THIS FORM, AND THE ORIGINAL SHOULD BE RETAINED BY THE RESEARCHER.

Academic Year 2004-2005 only

BIOGRAPHICAL SKETCH OF AUTHOR

Jungkeun Park was born on September 3, 1962 in Korea. He, as a chemistry major, received a B.S. degree from Chonbuk National University in 1985. He then studied Occupational Health at the School of Public Health, Seoul National University and earned a M.P.H. degree (thesis title: A study on working posture of video display terminal operators) in 1990. At the same year, he entered and worked for Korea Occupational Safety and Health Agency (KOSHA) over 10 years. In September 2000, Jungkeun enrolled the Work Environment Department at University of Massachusetts Lowell (UML) to pursue a master degree in Occupational Ergonomics. After receiving a M.S. degree (paper title: An investigation of occupational hazards in Dracut and Chelmsford dry-cleaning establishments), he continuously pursued a Sc.D. degree in September 2002 at the same department. While studying towards the degree, he worked as a teaching assistant for professors (Drs. Bryan Buchholz, Laura Punnett and Robert Karasek). He, as a research assistant, worked for Dr. Punnett at the Promotional Healthy And Safe Employment (PHASE) in Healthcare project in 2003 through 2005. Also he worked as a principal investigator (advisor: Dr. Buchholz) for the NIOSH-Harvard ERC project in 2005 to 2006. His current research interests include ergonomic exposure assessment, bioinstrumentation, musculoskeletal epidemiology, ergonomic job analysis, and ergonomics/industrial hygiene interventions.