QUANTIFYING THE PARTICIPATORY ERGONOMIC EFFECTS OF TRAINING AND A WORK ANALYSIS TOOL ON OPERATOR PERFORMANCE AND WELL-BEING

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ABSTRACT

Participatory ergonomics (PE) is a macroergonomics approach in which the end-users actively participate in developing and implementing the technology. PE can be an effective method for involving front-line workers in analyzing and redesigning their own jobs. PE can be used at the macro-level, the micro-level, or somewhere in between. At the macro-level, the focus of the PE program is across an entire organization or work system. At the micro-level, the focus of a PE approach is on a particular task, workstation, or product. A major benefit for using PE is that workers are more likely to accept changes to their job if they participate in the redesign. Furthermore, workers' motivation, job satisfaction, and knowledge are enhanced through the participatory process.

There are many case studies that describe successful PE approaches. These studies, however, lack a control group or comparison group and so changes in the workplace (e.g., a reduction of musculoskeletal injury) cannot be attributed directly to the interventions resulting from the PE program with certainty. Quantifying the effects of PE is difficult because of problems in trying to isolate variables. Confounding variables are often difficult to contain. This study quantified some of the effects of PE by utilizing a controlled experimental design in the laboratory in which participants analyzed and redesigned a manual material handling job. The effects of this PE approach were quantified by measuring a reduction of risk factors associated with the job and by measuring a lift index of the lifting task that indicates a risk for injury.

Many authors state or infer that some degree of ergonomics training should be given to the participants in a PE approach. However, the effects of providing ergonomics training to participants in these types of participatory approaches are unclear. This research evaluates the effects of providing the participants with basic ergonomics instruction relevant to the job being evaluated and redesigned. Also, this research suggests if the NIOSH lifting equation can be an effective tool in a participatory ergonomics approach in the redesign of a manual material handling job that involves lifting tasks. A 2-factor, between-subjects design was used.

Participants consisted of 32 volunteers (16 males and 16 females). Only individuals that have had no prior ergonomics knowledge were considered for the subject pool. Participants performed a simulated manual material handling job in the laboratory. After performing the job, some subjects were given ergonomics training and/or instructed on how to use the NIOSH lifting equation for manual lifting tasks. The participants were then asked to redesign the original job. The participants' redesigns were compared to the redesigns of the control subjects (who received no ergonomics instruction and did not use the NIOSH lifting equation).

The subjects who received the ergonomics instruction identified significantly more risk factors in the original job and eliminated significantly more risk factors in the redesign than the control subjects. The subjects who learned and used the NIOSH lifting equation also identified significantly more risk factors in the original job but did not eliminate significantly more risk factors in the redesign. The subjects who received the ergonomics instruction and who used the NIOSH lifting equation were not shown to have an advantage over the subjects who received the ergonomics instruction alone. The group that received the ergonomics training performed optimally with respect to the other experimental groups. Implications for participatory ergonomics approaches are discussed.

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Chapter 1. INTRODUCTION

Participatory ergonomics (PE) is a tool, method, or strategy commonly used with reference to macroergonomics (Hendrick and Kleiner, in-press). Macroergonomics is a sub-discipline of human factors engineering that is concerned with the analysis and design of work systems. A work system involves people interacting with hardware and/or software, internal environment, external environment, and organizational structures and processes. Macroergonomics attempts to optimize a work system through consideration of technical, personnel, and environmental variables and their interactions. Participatory ergonomics is a macroergonomics strategy that is used to involve the workers in designing or redesigning their own work. The participatory design/redesign can take place at an organizational or process level or as small as the task or product level. This research deals with quantifying the some of the effects of participatory ergonomics at the job and task level.

A fundamental philosophy of macroergonomics is that good *micro*ergonomic design cannot be achieved without first considering a large-system perspective. Even though effective ergonomic design is applied to a work station or task, the resultant system productivity and quality of work life may not be maximal because of inadequate attention to the macroergonomic design of the system (Hendrick, 1984). Since macroergonomic design leads to microergonomic design, this research concerns the final stage in the design process such that a macroergonomic system scan of the work system is already assumed. Therefore, the focus of this research concerns participatory design at the micro-level.

Background

Participation in human factors engineering and ergonomics. Employee participation in decision making and job design is a long-standing (e.g., Cotton, Vollrath, Froggatt, Lengnick-Hall, and Jennings, 1988). Cotton et al. performed a review of the literature on employee participation dating back to the 1940s. Participatory methodologies, however, have not been applied to ergonomic solutions until recently (Imada and Robertson, 1987) and participation in redesign has only been popular for the past 15 years or so. In the human factors and ergonomics discipline, user participation in design and redesign is referred to as participatory ergonomics (PE) or participatory design (PD). Though similar in concept, PE and PD seem to have evolved separately and in parallel within the human factors and ergonomics field. PE is more familiar with those in the macroergonomics and industrial ergonomics disciplines. PD, on the other hand, is identified with the human-computer interaction (HCI) researchers and the computer science discipline. Participatory design in HCI can involve usability testing for a computer-based user interface and for software design (e.g., Boy, 1996; Chin, Rosson, and Carroll, 1997) or even the design of a research laboratory (Snow, M., Kies, J., Neale, D., and Williges, R., 1996). Examples of participatory design in HCI ordinarily involve specialized, high-tech equipment. Participatory ergonomics, however, usually involves something broader like using worker involvement to redesign a manual material handling type task to reduce the risk of musculoskeletal injury. PE case studies have often been concerned with issues of health and safety. The research for this thesis is concerned with participation as discussed in the macroergonomics and industrial ergonomics literature (PE). As noted above, this type of participatory approach to design/redesign is referred to as participatory ergonomics. PE is a macroergonomics strategy to identify, analyze, and solve ergonomic problems (Imada, 1986 as cited by Robertson, 1991). In fact, a participatory approach to analysis and design is central to macroergonomics (Hendrick and Kleiner, in-press). There are several definitions for PE. For example, Nagamachi (1995) defines PE as the workers' active involvement in implementing egronomic knowledge and procedures in their workplace. Wilson and Haines (1997) define PE in the context of ergonomics management programs. They define PE as the involvement of people in planning and controlling a significant amount of their own work activities, with sufficient knowledge and power to influence both processes and outcomes. Since this research deals with worker participation at a micro/task redesign level, Imada's concept of PE best suits this study. Imada (1991) defines PE as one perspective in macrergonomics in which the end-users (the beneficiaries of ergonomics) are involved in developing and implementing the technology. Similar to Imada's interpretation for PE, the operational definition of PE for this study is *a method for involving front-line workers in analyzing and redesigning their own job*.

Rationale for participatory ergonomics. Workers are more likely to accept changes to their job if they participate in the redesign (e.g., Cohen, 1994; Cohen, 1996; Imada and Robertson, 1987; Imada, 1991; McNeese, Zaff, Citera, Brown, and Whitaker, 1995; Nagamachi, 1995; Wilson, 1995; Wilson and Haines, 1997). Lacking an effort to include the front-line workers in an organizational change can lead to the workers perceiving the change as a threat to job security or other negative consequences (Cohen, 1994). Imada (1991) gives three reasons as a rationale for using PE:

1. Ergonomics in many cases provides names and labels for ideas, principles, or practices that workers are already using and in a sense legitimizes the ideas and experiences that workers have accumulated in doing their jobs.
2. People are more likely to support projects for which they feel ownership. This often leads to greater commitment for changes to their workplace design.
3. User participation for developing technology creates a flexible problem solving tool; if people implement the technology, they will be able to modify it to solve future problems.

In addition to these points, workers' motivation, job satisfaction, and knowledge are enhanced with opportunities to provide input to decisions affecting their work methods (Cohen, 1996).

A conceptual framework for participatory ergonomics. Although there does not exist a unifying model for a participatory ergonomics, a general, conceptual framework can be applied to any participatory ergonomics approach. Figure 1 shows a general framework for developing and implementing a participatory ergonomics initiative.

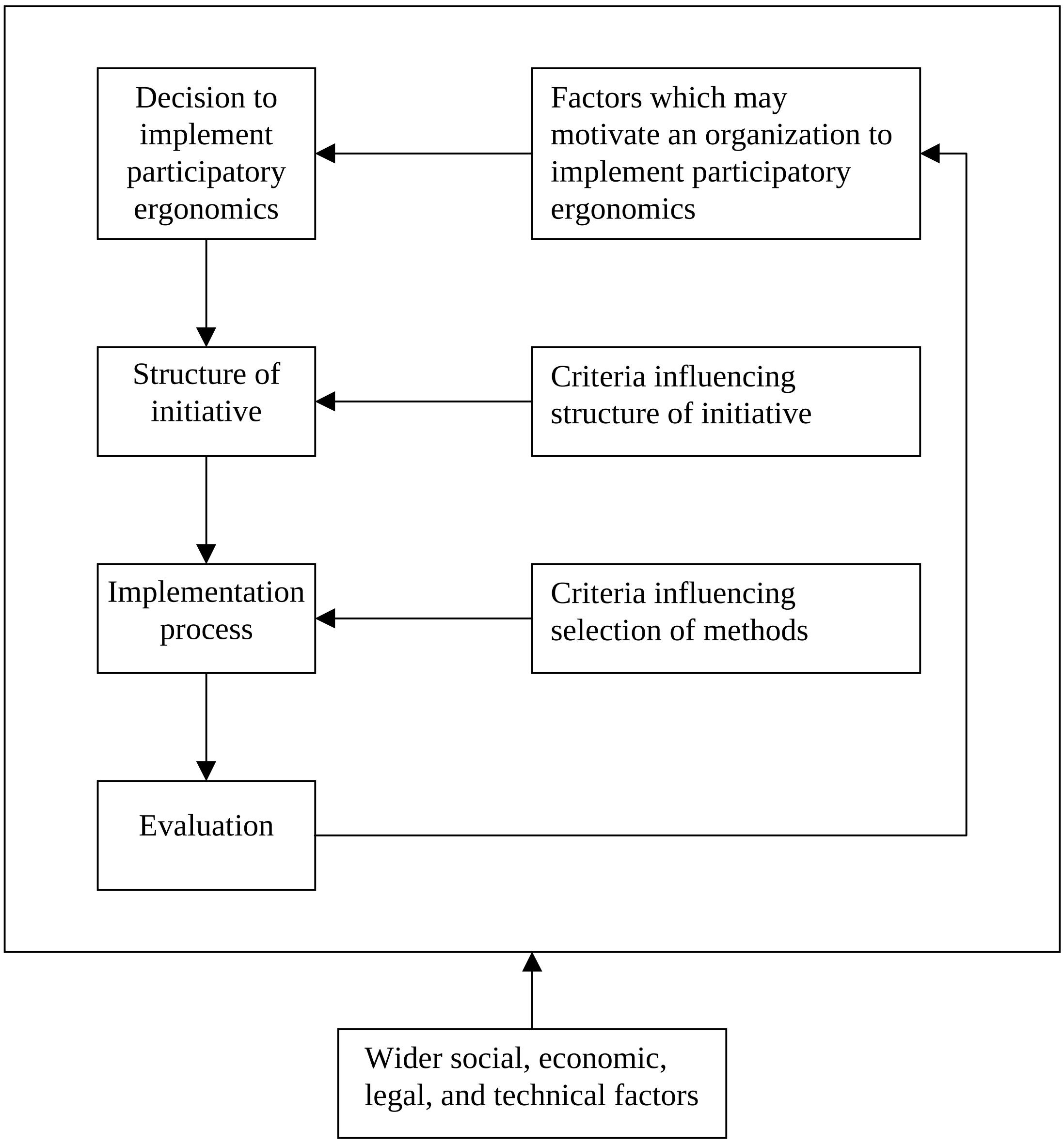

Figure 1. General Framework for Developing and Implementing a Participatory Ergonomics Initiative (adapted from Haines and Wilson, 1998)

This first general framework was developed Haines and Wilson (1998) to illustrate how an organization might initiate and structure a participatory ergonomics initiative. The structure of the initiative may be defined by the dimensions of PE described below. The following parameters for PE are based largely on the research of J. R. Wilson and H. M. Haines (Wilson and Haines, 1997; Haines and Wilson, 1998).

Dimensions of participatory ergonomics. A unifying model for PE does not exist. PE is a broad practice used in different forms and it contains a variety of methods and content (e.g., Brown, 1994; Vink, Lourijsen, Wortel, and Dul, 1992; Wilson, 1991). Wilson and Haines (1997) define the dimensions for PE as level, focus, purpose, timeline, involvement, coupling, and requirements.

The level and focus of any particular PE approach can be characterized as being macro or micro or somewhere in between (Nagamachi, 1995; Wilson and Haines, 1997). The macro-level of PE is similar to the macroergonomics strategy where the work organization is considered from a large system perspective. Participation at an organizational level is at the macro end of PE. Conversely, PE can be performed at the micro-level. At this level, a PE approach can be used in the redesign of a particular task, workstation , or product. The redesign of a particular process that involves the participation of those who work within that process is perhaps an example of PE somewhere between the macro- and micro-levels. The focus of a PE approach is closely related to the level (Wilson and Haines, 1997). The focus of a PE approach at the macro-level will be across an entire organization or work system. At the micro-level, the focus of a PE approach will be on a particular task, workstation, or product.

Purpose is another dimension of PE (Wilson and Haines, 1997). The purpose of a participatory program or exercise should be well defined. A PE approach in the workplace can be used for design, redesign, or implementation. If the purpose is misunderstood, the PE approach may be counterproductive.

The timeline of a PE approach can be continuous or discrete (Wilson and Haines, 1997). If workers are involved in the participatory process on a daily basis, the timeline is continuous. If workers participate on the redesign of one particular task, than the timeline will be discrete.

Involvement and coupling are related dimensions of PE that can vary quite a bit with any particular PE approach. Involvement refers to those involved in the participation. Wilson and Haines (1997) classify involvement as either direct or representative. Full direct participation is when all of those affected by the decisions become participants. Partial direct participation is more likely where those affected are represented by a subgroup of users. Representative participation, on the other hand, primarily occurs in a research laboratory where subjects are selected from a general population to reflect the likely users of a workplace design or product being evaluated.

In addition, participatory methods can remotely or directly coupled (Wilson, 1991; Wilson and Haines, 1997). Directly coupled methods involve little filtering or the participants' views and recommendations. Remotely coupled approaches involve some translation of participants' ideas and suggestions. Several authors describe different classifications for this dimension. Fuchs-Kittowski & Wenzlaff (1987) view participation as consultative, representative, or consensus-oriented. With consultative participation, users express ideas but the decisions rest with management. For representative participation, elected staff members participate in the development but management still makes the decisions. In consensus-oriented participation, all of those involved express ideas and decide on action through discussion. Vink et al. (1992) discusses two participatory approaches. In one, workers are trained to select improvements themselves. This method is directly coupled; the participants' recommendations are not filtered. In the other, the workers generate ideas and an expert (ergonomist) advises on a final selection. In this case, the participants' views and suggestions are filtered or translated by an expert.

The requirements of a PE approach is also a dimension. Participation can be either voluntary, imposed, or necessary (Wilson and Haines, 1997). Voluntary participation is most common, but participation can be imposed if involvement in continuous improvement programs, for example, is part of the job specification. Participation is considered necessary if resources allow for no other way of changing the workplace (Kogi, 1991).

Requisites of participatory ergonomics. Nagamachi (1995) gives requisites for a successful PE approach that fall into the following four categories: participation, organization, ergonomic methods and tools, and job design concept. Participation in redesign yields several benefits, the most important being greater worker commitment to the redesign. Commitment from the entire organization is also necessary for any PE approach. The organization must be willing to provide sufficient support and sufficient resources for the PE program. The organizational climate should not be hostile and a PE approach should not be introduced in circumstances of conflict, unrest, or great uncertainty (Wilson and Haines, 1997). A PE approach to redesign should use ergonomic methods and tools. Participants should be taught the basic ideas of ergonomics so that they can use that knowledge for redesign. The training could vary from training in general ergonomics principles to coaching in specific ergonomics skills that the participants will use within the participatory process (Haines and Wilson, 1998). Devereux, Buckle, and Haisman (1998) showed that poor redesign can occur when participants do not use ergonomic knowledge at all stages of a participatory process. Finally, the job design concept should be understood by all involved. In other words, the dimensions of the PE method need to be defined. In addition to the requisites given by Nagamachi for a successful PE approach to redesign, Wilson and Haines (1997) also give the use of a facilitator as a requirement for a PE approach. A facilitator should be unbiased yet knowledgeable about the organization, job, process, workplace, task, or product being redesigned.

<u>Tools and techniques for participatory ergonomics</u>. There are over 30 tools and techniques that have been used for PE. Wilson and Haines (1997) conveniently list these techniques and methods in a table with the references they come from. Some of these tools and techniques were developed and used with participatory ergonomics specifically in mind and others include those used in traditional ergonomics initiatives which have applied within a PE approach (Haines and Wilson, 1998). These tools and techniques can be used to provide a way for the participants to use their own knowledge and expertise to analyze a job and redesign. Examples of PE tools and techniques include quality circles, focus groups, checklists, concept mapping, and layout modeling and mock-ups. The use

of a tool or technique depends on the level of worker involvement and how directly the participatory method is applied. The tools and techniques used in a case where a participatory group's role is primarily that of validating an existing redesign may vary from those used to teach non-expert participants to analyze workplaces, generate new ideas, and evaluate changes for themselves (Haines and Wilson, 1998). Examples of some PE studies that use varying tools and techniques include one that shows how Canadian police officers participated in the redesign of the interior of the patrol car (Kourinka, Cote, Baril, Geoffrion, Giguere, Dalzell, and Larue, 1994). The participants were divided into subgroups and were free to choose their "preferred method" of expressing ideas about a better interior car design. In a PE approach to redesign the work of scaffolders (Vink, Urlings, and van der Molen, 1997), the scaffolders completed a checklist to identify problems and developed suggestions for improvements during "solution sessions". In these solution sessions, the 'nominal group technique' (NGT) was used as a participatory tool for the workers to generate ideas for redesign (Urlings, Vink, and Wortel, 1994). In a study done in the winding department of a synthetic fiber sector of a chemical plant, a "work team" was formed in an attempt to solve production problems (Maciel, 1998). This work team was comprised of 12 operators (4 from each shift) and was semi-autonomous. The team was without supervision; they decided how and when to work. In another example, Pankakoski (1998) describes a simulation method called the Work Flow Game that is a participative social simulation game based on face-to-face interaction of people having their real professional roles in the simulation. Each of these examples of studies that use worker participation showed positive results by using a participatory approach to redesign. For further examples, the reader should see Haines and Wilson (1998) for a comprehensive a list of participatory ergonomics case studies and the tools/techniques that were used for each of them.

The role of the ergonomist. In participatory approaches, an "expert" or ergonomist may have a varying role. If the participants receive expert ergonomics training, an ergonomist may not be needed during the participatory approach, except in setting up the participatory approach and in the ergonomics training for the participants. In other cases, an expert may have to be involved in all of the procedures (Haines and Wilson, 1998). Another approach could let the participants develop a redesign(s) themselves and have the "expert" or ergonomist validate and/or check feasibility of proposed solutions and even select a final solution at the end of the participatory process (Vink et al., 1992). The role of the ergonomist depends on the structure and dimensions of the particular participatory approach and also on the level of ergonomics training the participants receive.

Problem Statement

Motivation. There is little information in the literature on quantifying the effects of participatory ergonomics. Several case studies performed in the field have provided insight on PE approaches to job redesign. These studies, however, lack a control group or comparison group (e.g., Gjessing, Schoenborn, and Cohen, 1994). This study attempts to quantify some of the effects of PE by utilizing a true experimental design in the laboratory. Quantifying the effects of participatory ergonomics is difficult because of the problems in trying to isolate variables. Confounding variables are often difficult to contain (Buckle anf Li, 1996). This study quantifies some aspects of participatory ergonomics by manipulating ergonomics training and the PE tool that is used to redesign a manual material handling job.

A secondary motivating factor is to see how PE can contribute to reducing the risk of musculoskeletal injury due to manual lifting tasks. Low-back injury is a concern for workers who perform manual lifting tasks. Back problems are the most numerous of occupational injuries (Chaffin, Anderson, and Martin, p. 9) and result in staggering workers' compensation costs. PE approaches have been used to analyze and redesign occupational tasks that contribute to musculoskeletal disorders (reviewed in Chapter 2). All of these approaches, however, were case studies in the field. As noted above, this study attempts to quantify some of the effects of PE by utilizing a true experimental design in the laboratory.

Ergonomics training as a requisite for PE? A participatory approach to redesign can come in many forms. Many authors state or infer that one of the requisites for any participatory ergonomics approach is for the participants to receive proper ergonomics training (e.g., Devereux et al., 1998; Gjessing et al., 1994; Kournika et al., 1994; Nagamachi, 1995; St-Vincent, Kuorinka, Chicoine, Beaugrand, and Fernadez, 1997; Wilson and Haines, 1997). Participants should have to learn the knowledge and methods of ergonomics relevant to the process, task, or product being redesigned. Wilson (1995) states that "ergonomics experts" should give participants the tools and techniques and related training to make ergonomic interventions and to ensure that the training comes at the right time. One case study reported that a tool had not been subject to ergonomics during its participatory design (Devereux et al., 1998). This tool was designed by the workforce to reduce the physical strain caused by the manual handling of gas cylinders. The tool showed few benefits and may increase physical strain. The case study concludes that a participatory approach to design should use expert ergonomics at all stages of the participation process. The degree of competence of the workers, and therefore their knowledge, is a key factor for success in a participatory approach (Wilson, 1995).

Like the case study described by Devereux et al. (1998), there are other cases where basic ergonomics knowledge was not taught to the workers participating in the redsign. For example, in a PE approach to redesign the work of scaffolders described by Vink et al. (1997), workers participated in each step of the redesign process as directly as possible, but did not receive any training in the ergonomics knowledge relevant to scaffolding work. All of the scaffolders completed checklists to identify risk factors and risk tasks in the work, developed suggestions for improvements, tested improvements, and gave their preference. In the PE approach used in this case, the scaffolders' ideas and suggestions are *remotely coupled*. That is, the scaffolders' ideas and suggestions were filtered by a steering group chaired by the manager of the department. The steering group eliminated a portion of the suggested improvements based on feasibility before asking the workers for their preferences. Had this PE approach been directly coupled, the scaffolders would have had the power to redesign the work and select the final changes themselves. In a directly coupled approach, however, the scaffolders would certainly have needed proper training in the knowledge and methods of ergonomics relevant to scaffolding work. The PE approach described by Vink et al. (1997) used in the redesign scaffolding work was successful. The redesign of the work gave a decrease in workers' heart rate and shoulder load (Vink, et al., 1997). However, had the scaffolders received training in the ergonomics relevant to their work, would the improvements have been even greater? Is the ergonomics training of participants a necessary requisite in any PE approach? More likely, the use of ergonomics training or the level training depends on the structure and dimensions the participatory approach being used. The use of ergonomics instruction for the participants is one part of PE this research examines.

Content of the ergonomics instruction. For those case studies in which some type of training was given to the workers, basic ergonomics knowledge was taught. The level of training should not be too high, which is not realistic, but not too low, which may lead to trivialities (St-Vincent et al., 1997). Nagamachi (1995) gives a broad overview of the knowledge that workers should be taught. He categorizes the knowledge of ergonomics as (1) the structure of the human body, (2) energy expenditure in body movement, (3) an ergonomic implication of working posture, (4) fatigue and prevention of fatigue, (5) ergonomic relations between human, equipment, and process of work, (6) the psychophysical implication of job satisfaction, and (7) the know-how of improving jobs. This comprehensive list, however, is meant to be taught to workers participating in an organizational-wide PE program designed to continuously review a variety of process and tasks. When a PE approach is being used for a specific task, only ergonomics knowledge relevant to the task being analyzed need be taught. For example, in the participatory redesign of the interior of a police patrol car with reference to low-back pain, the basics of the biomechanics of seating, back structure, and related topics were taught (Kuorinka et al., 1994). In PE interventions in meat packing plants to reduce the incidents of musculoskeletal disorders, workers were taught information related to musculoskeletal disorders, musculoskeletal risk factors, and ergonomics principles on how to prevent these injuries (Gjessing et al., 1994).

Ergonomics instruction for a PE approach to redesigning a job that involves lifting can be partially derived from the practice of worker training for manual material handling. The NIOSH (National Institute for Occupational Safety and Health) Work Practices Guide for Manual Lifting (1981) outlines a program for training for safety in lifting. The general aims of this program are to make workers aware of the dangers of improper lifting, to show workers how to avoid unnecessary stress, and to teach workers how to become aware of what they can lift safely (NIOSH, 1981). Ergonomics instruction is used in this experiment is partially based on NIOSH's guidelines for training for safety in lifting (NIOSH, 1981), the training content given by Chaffin et al. (1999), and a booklet on basic ergonomics design principles for the workplace (Kennedy, MacLeod, and Adams, 1996). Chaffin et. al lists a modified version of the NIOSH program (p. 511). Of particular importance in the ergonomics instruction that is used for this study is training in identifying risk factors. The ergonomics instruction used for this study in outlined in Appendix B.

A tool for participatory ergonomics. Whether ergonomics training in a participatory approach to redesign is necessary or not, a tool or technique is needed for the participants to use to analyze a job and redesign. There are many tools and techniques that have been used for PE. Examples of tools and techniques that have been used for PE were described above. There is no literature that describes a PE case study in which the NIOSH lifting equation was used a PE tool for analysis and redesign of a job by *non-ergonomists* (or "non-experts"). The NIOSH lifting equation was designed to identify manual lifting tasks that put the worker at a risk for injury. The equation was designed to be easy to use and is an ideal method for workers to use since it involves only basic mathematics. This equation for manual lifting can be used to quantify redesigns of the lifting tasks.

<u>The NIOSH lifting equation</u>. Originally developed by a committee of experts in 1981 and later revised in 1991, the NIOSH lifting equation is used for the design and evaluation of manual lifting tasks. The NIOSH lifting is used to compute a recommended weight limit (RWL) for manual lifting. A lifting index (LI) of relative physical stress can then be used to identify hazardous lifting tasks (Waters, T. R., Putz-Anderson, V., Garg, A., and Fine, L. J., 1993). The NIOSH equation is based on biomechanical, physiological, and psychophysical criteria. The biomechanical criterion deals with stress on the low-back during lifting. The physiological criterion is concerned with maximum aerobic capacity to control fatigue for repetitive lifting. The psychophysical criterion is based on data defining strength and capacity to perform manual lifting at different frequencies for different durations of time. For an in depth description of these criteria and the expert panel's rationale behind them, the reader should refer to Waters et al. (1993). Appendix C gives the NIOSH lifting equation, a description of all of the equation's multipliers and terms, and associated tables. In addition to using the NIOSH lifting equation to analyze a lifting task, the equation can

help the user in redesigning the task as well by “working backwards”. The user can see which of the equation’s multipliers are low after using the equation. Each multiplier corresponds to a specific design parameter of the lifting task. Low multipliers suggest that the corresponding design parameters are poorly designed. Logically, these are the design parameters that should be focused on in a redesign.

Research Objectives and Research Questions

There are three primary objectives for this study:

(1) Quantify and understand the effects of ergonomics instruction in a participatory ergonomics approach on the redesign of a manual material handling job.

(2) Determine if the NIOSH lifting equation can be an effective tool for a participatory ergonomics approach in the redesign of a manual material handling job that involves lifting tasks.

(3) Determine if the combination of ergonomics training and the NIOSH lifting equation provides the optimal approach to the participatory redesign of the manual material handling job.

By pursuing the research objectives, the following question is addressed: Does this particular participatory ergonomics approach really improve design performance? And if so, why?

Research Hypotheses

1. The subjects who receive the ergonomics instruction will be able to redesign the original job with a significantly lower lift index than the control subjects.

2. The subjects who receive the NIOSH lifting equation will be able to redesign the original job with a significantly lower lift index than the control subjects. Furthermore, these subjects will be able to redesign the job with a lower lift index than the subjects who receive only the ergonomics instruction.

3. The interaction effects will not be significant. Furthermore, there will be no advantage to having both the instruction and the NIOSH lifting equation over just one of them. The subjects who receive both the ergonomics instruction and the NIOSH lifting equation will not be able to redesign the original job with a even greater significance than those subjects who receive just one of the conditions.

4. The subjects who receive the ergonomics instruction will be able to identify and eliminate significantly more risk factors during the analysis and redesign than the control subjects.

5. The subjects who receive the NIOSH lifting equation will be able to identify and eliminate significantly more risk factors during the analysis and redesign than the

control subjects. Furthermore, these subjects will be able to identify and eliminate more risk factors than the subjects who receive only the ergonomics instruction.

6. The interaction effects will not be significant. Furthermore, there will be no advantage to having both the instruction and the NIOSH lifting equation over just one of them. The subjects that receive both the ergonomics instruction and the NIOSH lifting equation will not be able to identify and eliminate more risk factors with a even greater significance than those subjects who receive just one of the conditions.

7. Subjects who receive the ergonomics training and/or the NIOSH lifting equation will give a higher average satisfaction rating for performing the redesigned task with respect to performing the original task than the average satisfaction rating given by control group. However, there will be little difference amongst the average satisfaction ratings given by the experimental groups.

These hypotheses are based on the belief that the NIOSH lifting equation can be used by the participants as an effective PE tool in the redesign of a manual material handling job. Keyserling and Hankins (1994) find that a non-ergonomics expert (like the participants of this study) will need a tool that is structured to include the systematic consideration of various risk factors. The NIOSH lifting equation provides a structured way of identifying potential the risk factors of a lifting task through the equation's multipliers. Each of the equation's multipliers corresponds to an element of the design of the lifting task. A low multiplier suggests that the corresponding element of the lifting task is a risk factor.

Providing the participants with this relatively simple and structured analysis tool should allow them to identify and eliminate more risk factors and redesign the lifting tasks with a lower lift index than the control subjects.

The participants who receive the ergonomics instruction are also expected to perform significantly better than the control subjects based on the case study described by Deveaux (1998). However, they are not expected to perform as well as the subjects who receive the NIOSH lifting equation since the ergonomics instruction does not provide a highly structured technique for analyzing the lifting tasks. Finally, the participants who receive both the NIOSH lifting equation and the ergonomics instruction are not expected to have an advantage over those participants who receive just one of the conditions. This result is expected because the experimenter has no basis for predicting that the combination of the instruction and the NIOSH lifting equation will allow subjects to perform significantly better than those subjects who receive only one of the conditions.

Chapter 2. REVIEW OF THE LITERATURE

Part of the previous chapter reviewed the participatory ergonomics literature as it applies to the general framework of participatory ergonomics. The following, in contrast, is a review of the literature and case studies that deal with PE approaches to evaluate and redesign manual material handling jobs in an effort to reduce the risk of musculoskeletal injury. The musculoskeletal injuries discussed in these case studies from cumulative trauma disorders (CTDs) or low back injury. For each case study, the PE tool that is used will be described. Also, the use or non-use of some type of ergonomics training will be noted.

Case Studies of PE Approaches to Reduce the Risk of Musculoskeletal Injury

Liker et al. (1989) describes PE programs that were used in two U.S. and two Japanese manufacturing plants. All four PE programs focused on the redesign of repetitive manufacturing jobs to reduce physical stress on workers through the reduction of risk factors associated with the jobs. In these PE programs, the participating groups were comprised mostly of managers, engineers, and other “experts”. Actual front line workers were included only in a limited fashion. In both the U.S. and Japanese plants, the workers, whose jobs were redesigned, had a voice only indirectly through a supervisor or directly, but only by providing their input in a consultative fashion. All four of the PE programs were successful in making significant numbers of job changes. However, little is mentioned about the reduction of risk factors for musculoskeletal injury in these jobs. In all for cases, the groups did receive some type of training. At one of the

Japanese plants, for example, the group received training in working posture analysis, which was the focus of the ergonomics effort.

In a liquor distribution center, a participatory ergonomics project was used in an attempt to prevent low back pain in manual material handling (Patry, Costa, and Kuorinka, 1993). In this approach, labor and management representatives combined and formed into small working groups. The working group used a generic problem solving process which qualifies as the PE tool that was used for this approach. The participants did receive some form of ergonomics training as a means for identifying risk factors for stressful back postures. Changes to the work place were made based on the recommendations of the participants. Patry et al., however, did not discuss the potential benefits of these changes or a reduction of risk factors for injury. A reduction in the incidents of musculoskeletal injury cannot be apparent until much time has passed but a reduction in the number of risk factors is an alternative method for measuring the success of a PE approach (Buckle and Li, 1996; Cohen, 1994).

St-Vincent et al. (1997) describes participatory ergonomics projects that were used in two plants that produced electrical consumer products and telecommunications equipment. The aim of these projects was the prevention of musculoskeletal disorders. A group was formed in each plant that was made up of the operators and technical specialists. Each group did receive ergonomics training prior to the analysis of the work tasks. After identifying the work tasks that had a high risk for musculoskeletal injury, the group used a structured ergonomic work analysis procedure. This work analysis procedure was the PE tool for this approach. In this structured work analysis procedure, the group identified the risk factors associated with the tasks and determined the causes of these risk factors. Finally, the group brainstormed potential solutions. St-Vincent et al. used the formalized work analysis procedure as a PE tool with the belief that the initial ergonomics training given to the participants is not sufficient to allow the group to apply an ergonomics approach autonomously. In fact, an ergonomist was closely involved in the analysis and solution finding with the group for the first job before distancing himself for the analysis and solution finding for the subsequent jobs. 50 solution items were implemented as a result of the PE project. In 78% of the cases, the magnitude of the risk factors were reduced and only 14% of the cases showed no visible impact on the risk factors. In the remaining 8%, it was impossible to evaluate the impact of the solutions on the risk factors.

A team used surveys and checklists as a PE tool in a PE program used in a meat packing plant (Moore and Garg, 1997; also described in Gjessing et al., p. 93-161). These surveys and checklists were used to identify musculoskeletal and safety-related risk factors. The PE program was implemented in 1986 and the effectiveness of the program was monitored from 1988 to 1993. The program's effectiveness was monitored by collecting yearly measures on the crude incidence rate, lost-time incidence rate, severity rate (incurred losses), recordable musculoskeletal conditions, and workers' compensation costs. Measuring the effectiveness of a PE program in this manner is in many cases impractical since it can take many years to observe a significant change in these types of statistics. A reduction of risk factors is commonly used as an alternative method. Over the six years, there was an increase in the crude incidence rate and the lost time incidence rate. The authors suggest that the increases are due to employee training in early recognition and reporting of musculoskeletal injuries. There were no significant changes in severity rate or recordable musculoskeletal conditions. The plant did experience significant decreases in annual workers' compensation costs. It cannot be proved that the changes over the six year time period can be were caused by the implementation of the PE program because there were no control or comparison groups (the results were purely descriptive). The teams that participated in the redesigns of the jobs were given training that included information on musculoskeletal disorders and their associated risk factors.

Halpern and Dawson (1997) describe a PE program that was implemented in an automobile products manufacturing plant. The program was introduced in an effort to reduce workers' compensation costs by reducing the incidents of musculoskeletal disorders. The tasks that were analyzed were machine sewing tasks of canvas automobile accessory parts. The nature of the job makes the works susceptible to cumulative trauma disorders (CTDs) because of high pinch forces and awkward wrist postures. The participants in the redesign team included a mixture of production supervisors, production employees, and engineering personnel. Traditional ergonomics methods were used as the PE tool. These methods included a task analysis, force measurements, postural analysis, and quantification of repetitive tasks. After the current tasks were analyzed, the redesign team was given a training seminar on ergonomics principles, risk analysis techniques, and workstation design guidelines in order to refine the preliminary job re-design recommendations. The effectiveness of the program was monitored for 3 years after the implementation of the program. The authors reported an increase in the number of claims but like Moore and Garg (1997), the authors suggest this increase is due to increased employee awareness as a result of basic ergonomics training. The authors report a decrease in workers' compensation losses. Like Moore and Garg (1997), however, these results are purely descriptive since no control group was used. Changes in the musculoskeletal disorder statistics could have been influenced by external factors.

The Lack of an Academically Rigorous Approach.

There are other case studies in which a PE approach was used in an effort to reduce the risk of musculoskeletal injuries (e.g., van der Molen, Hoonakker, Scchreurs, Bulthuis, Brouwer, and Binkhorst, 1993; Gjessing et al., 1994; Vink et al., 1997; Devereux et al., 1998). In these case studies and with the ones discussed above, the PE approaches that were used differ considerably with the PE dimensions described in Chapter 1. Regardless of the structure of the PE approaches, there is a lack of an academically rigorous approach in quantifying the effects of participatory ergonomics. These studies lack a control group or comparison group and so changes in the measures that were used cannot be attributed directly to the interventions undertaken with certainty (e.g., van der Molen et al., 1993; Halpern and Dawson, 1997; Moore and Garg, 1997). This study attempts to quantify some of the effects of PE by utilizing a true experimental design in the laboratory. Quantifying the effects of participatory ergonomics is difficult because of the problems in trying to isolate variables. Confounders may be difficult to control (Buckle anf Li, 1996). This study quantifies some aspects of participatory ergonomics by manipulating ergonomics training and the PE tool that is used to redesign a manual material handling job. The hypotheses outlined at the end of Chapter 1 are tested by the research design described in the following chapter.

Chapter 3. METHODOLOGY

The Participatory Ergonomics Model

The participatory ergonomics model used for this experiment is specified with respect to the dimensions of PE described earlier. The *level* of this PE study is on the micro-level with the *focus* being on the redesign of a manual material handling job with several lifting tasks. The *timeline* is a discrete one. *Involvement* is representative, with subjects selected from a student population so as to reflect the likely users. The participative methods are *directly coupled*; the participants redesign the job with no filtering of their recommendations. The participation is *voluntary*. Also, since a manual material lifting task is usually performed by one worker, subjects analyze and redesign as individuals rather than in groups.

Subjects

Participants consisted of 32 volunteers (16 males and 16 females, balanced across gender). Only non-engineering students that have no prior formal ergonomics instruction and no prior knowledge of the NIOSH lifting equation were considered for the subject pool. Furthermore, the subjects were screened by their work experience so that no subjects used have worked for a company in which they have performed similar manual lifting tasks like the ones used in this experiment. All subjects are at least 18 years old. Each subject falls in the 10^{th} to 90^{th} percentile range for the U.S. population for stature. The range is from 10^{th} percentile female to 90^{th} percentile male or 5'1" to 6'1/2" based on anthropometic data in Kroemer, Kroemer, and Kroemer-Elbert (1996) on page 30. This was done to avoid extreme cases where the performance of the tasks is altered based on a subject's stature. Each participant attended two consecutive experimental sessions. Each session lasted 1-2 hours. In order to recruit participants, advertisements of the study were posted. Subjects received $10 for completing the first session and $15 for completing the second. All participants were instructed that they were free to withdraw from the study at any time without penalty. None of the subjects chose to withdraw. Data gathered as part of this experiment is treated with confidentiality. Subjects read and signed the informed consent listed in Appendix E.

Pilot Subjects. Before the actual experiment, three pilot subjects were recruited to participate. The three pilots received both the ergonomics instruction and the NIOSH lifting equation conditions. The first pilot was used to help improve the experimental procedure. The next two pilots are considered "experts". These two pilots are graduate students in the Human Factors and Ergonomics Center at Virginia Tech. The experts' data is meant to represent the case where management has implemented a redesign of the job without participation from their own workers. It is assumed that the redesign implemented by management would have been developed by their own ergonomists or by consultants with similar knowledge to that of the graduate students who served as pilots for this study. The experts' data is compared against the data from the regular subjects. By comparing the time to redesign, quality of the redesign, and satisfaction, insight can be gained on the potential benefit of the participation itself.

Experimental Design

The experimental design is a two-factor, between-subjects design. The 2 x 2 experimental design is shown in Figure 2. Independent variables are treated as fixed-effects variables and the subjects are treated as a random-effect variable.

		INSTRUCTION (B)	
		Given (b1)	Not Given (b2)
TOOL (A)	Given (a1)	S_1-S_8	S_9-S_{16}
	Not Given (a2)	S_{17}-S_{24}	S_{25}-S_{32} *(control)*

Figure 2. Experimental Design

Independent variables. The two factors for the experimental design are instruction and tool. There are two levels for each of the independent variables. The levels for instruction and tool are "given" and "not given". For the instruction-given condition, subjects received basic ergonomics instruction relevant to the experimental tasks being performed. The subjects used this ergonomics knowledge while redesigning the job. For the tool-given condition, subjects learned and used the NIOSH lifting equation as a tool to redesign the job.

Dependent measures. The following dependent measures were collected during the experiment:

(1) lift index

(2) number of risk factors identified

(3) number of risk factors eliminated

(4) heart rate

(5) time to redesign

(6) satisfaction

(7) postural discomfort

The *lift index* for each subjects' redesign was computed. The lift index is a ratio of the actual load used in the lifting task over the recommended weight limit. The recommended weight limit for the lifting task is computed by using the NIOSH lifting equation. The experimenter used the NIOSH lifting equation to compute the lift index for each subjects' redesign independent of subjects using the NOISH lifting equation as a tool for redesign. The lift index is used as an indication of the quality of the lifting task redesign relative to the original design.

The *number of risk factors identified* and the *number of risk factors eliminated* both serve as dependent measures. In the case of musculoskeletal disorders, it may take some time for any reductions to show. Alternatively then, a reduction of risk factors or levels of exposure to them can be used as a valid measure of the effectiveness of a PE approach (Buckle and Li, 1996; Cohen, 1994). These measures help gauge if one independent variable allows subjects to identify and/or eliminate more risk factors than the other independent variable. A list of the risk factors that have been designed into the original job are listed on the score sheet in Appendix H.

Each subject's *heart rate* was monitored and recorded throughout the entire experimental process. Heart rate data from performing the original task is compared to that of the redesigned task in the hope of gaining insight as to which of the jobs is more difficult to perform physically. Heart rate was also recorded during the redesign phase to see if any insight could be gained about the mental workload of the redesign task.

The amount of *time* each subject takes *to redesign* the job was measured. The experimenter was interested if one group of subjects uses significantly more time to redesign the original task than another group of subjects or the experts.

Subjects were asked rate their *satisfaction* and *postural discomfort* with performing the redesigned job with respect to the original job. Since all 32 subjects and the two experts first performed the original job, satisfaction and discomfort ratings were collected from all them to determine if any insight could be attained as to which of the experimental conditions was most preferred.

Facilities, Equipment, and Materials

The experiment was performed in the Macroergonomics and Group Decision Systems Laboratory (MGDSL) in the Industrial and Systems Engineering Department (ISE) of the Virginia Polytechnic Institute and State University. The MGDSL is divided into four rooms. Room number 563 was the main experimental room for the experiment.

Materials for the experimental job set-up included adjustable shelving, boxes, a dolly, and a push-cart. The main adjustable shelving apparatus has shelves adjustable in

1” increments without the use of any tools (Shelving By Design™). A smaller adjustable shelving set was also used. In addition to the adjustable shelving, non-adjustable shelves that lined three of the four walls in the experimental room were used.

In addition to the equipment and materials for the manual material handling portion of the experimental tasks, a computer workstation with an online program was used for presentation of the NIOSH lifting equation from the Internet (Russel, 1998). Subjects also used this computer workstation for data entry. A 30-foot tape measure and a goniometer were used to help analyze the task when applying the NIOSH lifting equation. Also, a data projection system was used to present the ergonomics instruction for the participants.

A heart rate monitor (Polar Vantage NV™) was used to continuously record each subject’s heart rate. The heart rate monitor’s transmitter was strapped around each participant’s chest and a receiver was worn around the wrist. After the experiment, the heart rate date was downloaded into a computer using the Polar Advantage Interface System™.

Procedure

Pre-experimental procedure. Subjects read and signed the informed consent included in Appendix E. The subjects were then asked to complete a demographics sheet (Appendix F). Then the subjects were given an overview of the experiment.

Conditions. The subjects received one or both of the experimental conditions (ergonomics instruction and the NIOSH lifting equation) prior to performing the original job. The control subjects received neither. Subjects who received the instruction condition were taught the instructional content listed in Appendix B. They were given a slide presentation of the content and some of the points were demonstrated for the participants by the experimenter (instructor). For example, the experimenter physically demonstrated various risky postures. A 20-question true/false test was given after the instruction to ensure that the subjects had sufficiently acquired the knowledge given in the presentation (Appendix G). If a subject had not demonstrated that he/she had acquired the knowledge to a certain criterion level, the subject would have received the instruction again until the subject had demonstrated sufficient acquisition of the ergonomics instruction. All subjects who received the ergonomics instruction passed the test of knowledge after the first try. The passing criterion was 75% (15 or 20 questions correct). All subjects scored at least 90% (18 of 20 questions correct).

Subjects who receive the tool condition were given the NIOSH lifting equation and were advised on how to use it before they analyzed and redesigned the job. Subjects used the equation through an online computer program (Russel, 1998). The program prompted the subjects for the necessary information about the lifting tasks. Subjects were told to use the output from the equation to help them redesign the job. The NIOSH lifting equation, its multipliers, and associated tables are listed in Appendix C. A test was given after the subjects had been advised on how to use the NIOSH lifting equation to analyze and redesign the job. For the test, the subjects had to use the NIOSH lifting equation to calculate the lift index of a sample lifting task. Subjects had to take measurements about the task with the tape measure and goniometer and enter this information into the online program. If a subject had performed this task incorrectly, the subject was advised again on the NIOSH lifting equation until the subject has demonstrated proficiency on the use of the equation.

The subjects who received the instruction condition had the same amount of preparation time as the subjects who received the tool condition. The ergonomics presentation and the presentation of the NIOSH lifting equation were each designed to last the same amount of time. Each subject, therefore, had about the same amount of preparation time before redesigning the original job. Differences in performance are then more easily attributed to the instruction vs. the tool. The subjects who received both conditions had twice as much preparation time. The control subjects needed no preparation time since they did not receive one of the conditions but they received the same instructions as the other subjects as to the purpose of the experiment.

Experimental job. The experimental job is modeled similarly to that of a UPS manual material handling job. Each subject initially performs the same original job. The subject is asked to move three shipments of six boxes each to a storage room, load them onto shelves, and then enter information about the shipments into a computer workstation. First, the subject loads a box onto a dolly in the loading area (room 567) which is located two rooms from the main experimental room (room 563). Figure 3 shows a subject loading a box onto the dolly.

Figure 3. Subject Loads Box on Dolly

Next, the subject transports the box with the dolly through an adjacent room (room 565) and into the main experimental room (Figure 4).

Figure 4. Subject Transports box to Storage Room

Then the subject rolls the box with the dolly into the main experimental room which is meant to represent a storage room. The subject is told that the box and dolly are not allowed to cross the plastic matted area in the entrance of the storage room; the plastic matted area is meant to represent a change in level with the rest of the floor in the storage room. The subject then unloads the box from the dolly (Figure 5).

Figure 5. Subject Unloads Box from Dolly

The subject then lifts the box from the dolly and places it on the shelves to his left. The subject is instructed to use a certain technique while placing the boxes on the shelves. The subject faces the wall directly in from of him, twists 90 degrees to his right to unload and lift the box from the dolly using a stoop lift, and then twists 180 degrees around to place the box on the shelves along the wall to his left (Figure 6).

Figure 6. Subject Places Box on Shelf

The subject places the box on the shelf and then goes back to the loading area in room 567 to load the next box from the first shipment. The subject repeats this task until three of the boxes are loaded onto the top shelf of the adjustable shelving system and three boxes are placed on the top non-adjustable shelf adjacent to the adjustable shelving system (Figure 6). After placing the six boxes of the first shipment onto the designated shelves, the subject then enters information about the shipment into an inventory form (Appendix A2) at the computer workstation pictured in Figure 7.

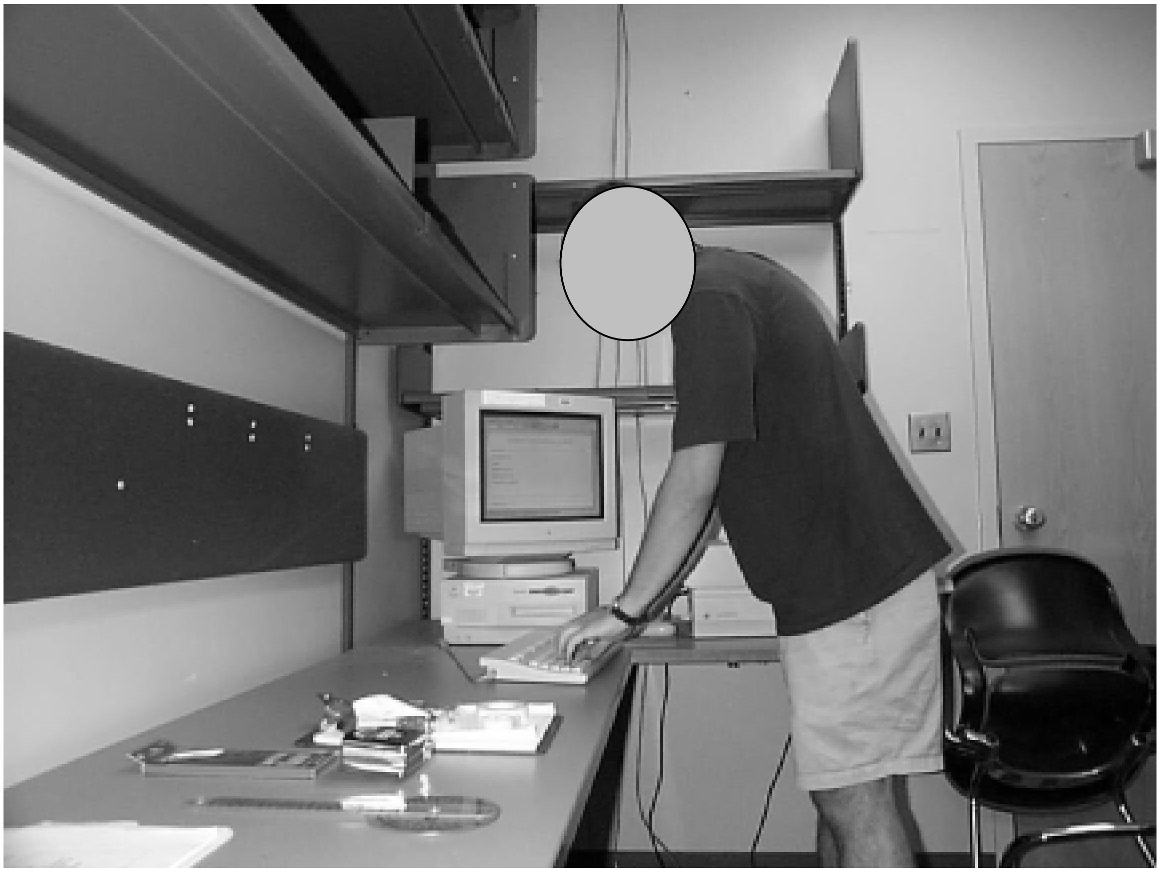

Figure 7. Subject Enters Data into Inventory Form at Computer Workstation

The information that the subject needs to enter into the inventory form is listed on the labels that appear on each box. While the subject enters this information into the computer, the experimenter removes the six boxes from the shelves and places them back in room 567 where they originally were. The subject then repeats the same tasks for two more shipments. The subject brings the dolly back out to the loading area to transport one box at a time for the next shipment. After the subject has finished entering the information into the computer for the third shipment, he then prints then inventory form and places it in the outgoing mail bin located next to the entrance of the storage room. The subjects are told to assume that each of the boxes weighs 22 lbs (10 kg). However, each of the boxes are empty to ensure the safety of the subjects since to lifting task was designed to be risky. If the boxes actually weighted 22 lbs, the subjects would be at risk for injury. Subjects were exposed to a 22 lb weight prior to performing the job so that they could get a feel for how much the boxes were supposed to weigh. The specifications of the lifting task and the boxes can be viewed in Appendix A1.

Risk factors. The experimental job was designed with 16 risk factors which are not confined to just the lifting task. A listing of these risk factors can be viewed in Appendix H. After subjects performed the original job and before they redesigned the job, they were asked to identify any risk factors they believe are associated with the original job. Subjects read instructions on identifying risk factors and recorded these risk factors on a sheet of paper (Appendix A3). From this list, the experimenter evaluated how many of the actual risk factors each subject was able to identify.

Redesign original job. Subjects redesigned the original job using the redesign instructions in Appendix A4. If the subject received the ergonomics instruction at the beginning of the experiment, he/she was allowed to refer to a copy of the ergonomics presentation during the redesign phase. If the subject learned the NIOSH lifting equation, he/she was instructed to use the equation to help analyze and redesign the lifting task. Subjects were told that they should physically implement any redesign ideas by moving shelves/objects around. For any redesign ideas that could not be physically implemented, subjects were instructed to list these on paper. Subjects were told that the only constraint for the redesign was that three shipments of six boxes must still be loaded into the storage room. While the subjects were redesigning the original task, the experimenter was in an adjacent room to eliminate potential bias.

Performance of the redesign. After the subjects had redesigned to job in the interest of making it safer, they performed the redesign that they had implemented. The subjects were timed as with the original job and their heart rate was again monitored and recorded.

Post-test questionnaire. Subjects received a post-test questionnaire after completion of the experiment (Appendix D). The questionnaire uses a Likert rating scale. Some questions vary depending on which condition(s) the subject received (Appendices D1-D4).

Chapter 4. RESULTS

Quantitative Data Results

The experimental model. As illustrated in Figure 2, the experimental design is a 2-factor, between-subjects design (2x2 factorial, completely randomized design). TOOL (A) and INSTRUCTION (B) are fixed-effects variables and subjects are treated as a random-effects variable. Therefore, the structural model for this design is:

$$Y_{ijkl} = \mu + \alpha_i + \beta_j + \gamma_{k(ij)} + \alpha\beta_{ij} + \varepsilon_{l(ijk)}$$

Where α corresponds to the factor TOOL and β corresponds to the factor INSTRUCTION.

And the expected mean squares are:

$$E(MS_A) = bn\sigma_\alpha^2 + \sigma_\gamma^2 + \sigma_\varepsilon^2 = 16\sigma_\alpha^2 + \sigma_\gamma^2 + \sigma_\varepsilon^2$$
$$E(MS_B) = an\sigma_\beta^2 + \sigma_\gamma^2 + \sigma_\varepsilon^2 = 16\sigma_\beta^2 + \sigma_\gamma^2 + \sigma_\varepsilon^2$$
$$E(MS_{AxB}) = n\sigma_{\alpha\beta}^2 + \sigma_\gamma^2 + \sigma_\varepsilon^2 = 8\sigma_{\alpha\beta}^2 + \sigma_\gamma^2 + \sigma_\varepsilon^2$$
$$E(MS_{S/AB}) = \sigma_\alpha^2 + \sigma_\varepsilon^2 = \sigma_\alpha^2 + \sigma_\varepsilon^2$$

and:

Sources of Variance	df	F-ratio
A	(a-1) = 1	$(MS_A)/(MS_{S/AB})$
B	(b-1) = 1	$(MS_B)/(MS_{S/AB})$
AxB	(a-1)(b-1) = 1	$(MS_{AxB})/(MS_{S/AB})$
S/AB	ab(n-1) = 28	
Total	abn-1 = 31	

Main dependent measures. Tables 1 and 2 show the data for the number of risk factors identified (RF I), risk factors eliminated (RF E), lift index (LI), time to perform the original job (T original), time to redesign the job (T process), and time to perform the redesign (T redesign). Refer back to the Methodology chapter on pages 29-30 for a description of how these dependent variables are measured. All of the time data in these tables is in minutes. The raw data for all of these dependent measures is also listed in Appendix I. Table 1 shows the data for the pilot study.

TABLE 1. Data recorded for the Dependent Measures from the Pilot Study.

Subject	Gender	**Type**	**RF I**	**RF E**	**LI**	T original	T process	T redesign
expert 1	F	expert	10	13	1.06	23	64	11
expert 2	F	expert	6	9	0.66	23	38	14
		TOTAL	16	22	1.72	46	102	25
		AVE	8	11	0.86	23	51	13

The two pilot subjects were the experts for this study. Table 2 lists the corresponding data for the 32 subjects that were used in the experiment.

TABLE 2. Data recorded for the Dependent Measures from the 32 Subjects.

Subject	Gender	**Type**	**RF I**	**RF E**	**LI**	T original	T process	T redesign
subject 01	F	control	5	6	2.34	22	42	12
subject 03	F	control	2	6	2.14	29	50	18
subject 07	F	control	0	8	2.15	24	25	18
subject 08	F	control	3	3	2.66	22	20	18
subject 16	M	control	3	5	3.06	25	23	23
subject 20	M	control	2	9	2.49	18	16	11
subject 22	M	control	2	6	1.47	19	27	13
subject 23	M	control	4	7	1.90	20	25	15
		TOTAL	21	50	18.21	179	228	128
		AVE	3	6	2.28	22	29	16

Subject	Gender	**Type**	**RF I**	**RF E**	**LI**	T original	T process	T redesign
subject 02	F	both	9	6	1.55	21	38	16
subject 05	M	both	8	7	1.98	26	43	18
subject 06	M	both	7	9	1.80	24	31	20
subject 09	M	both	10	10	2.47	17	23	10
subject 13	F	both	10	12	1.41	24	34	12
subject 18	F	both	4	8	1.33	25	74	22
subject 25	F	both	9	10	1.55	20	23	12
subject 29	M	both	5	12	1.13	20	27	16
		TOTAL	62	74	13.22	177	293	126
		AVE	8	9	1.65	22	37	16

(cont.)

Subject	Gender	Type	RF I	RF E	LI	T original	T process	T redesign
subject 04	F	tool	6	3	3.30	25	103	20
subject 10	M	tool	6	10	0.65	20	44	16
subject 12	F	tool	1	0	3.72	18	26	12
subject 17	F	tool	3	4	2.53	23	31	12
subject 19	F	tool	3	6	0.82	19	33	16
subject 24	M	tool	8	13	0.88	24	33	20
subject 26	M	tool	5	13	0.00	18	39	16
subject 30	M	tool	4	7	2.19	18	17	12
		TOTAL	36	56	14.09	165	326	124
		AVE	5	7	1.76	21	41	16

Subject	Gender	Type	RF I	RF E	LI	T original	T process	T redesign
subject 11	F	instruction	6	13	1.93	22	32	12
subject 14	F	instruction	9	13	1.43	22	29	18
subject 15	F	instruction	7	8	0.90	18	24	14
subject 21	F	instruction	4	9	1.46	21	23	7
subject 27	M	instruction	4	6	3.20	26	28	12
subject 28	M	instruction	7	13	1.48	20	27	8
subject 31	M	instruction	1	1	3.22	21	27	18
subject 32	M	instruction	6	10	1.76	19	16	7
		TOTAL	44	73	15.38	169	206	96
		AVE	6	9	1.92	21	26	12

The data in Table 2 is separated into four groups of eight subjects. Each group of eight corresponds to one of the four experimental groups. Subjects labeled with type “both” represent those subjects who received the instruction and the tool.

Table 3 summarizes the data by showing the mean and standard deviation by group for each of the main dependent measures.

TABLE 3. Mean and Standard Deviation by Group for the Main Dependent Measures

Risk Factors Identified			**Risk Factors Eliminated**		
	Mean	SD		Mean	SD
Control	3	1.51	Control	6	1.83
Tool	5	2.20	Tool	7	4.72
Instruction	6	2.45	Instruction	9	4.19
Both	8	2.25	Both	9	2.19

Lift Index			**Time to Redesign the Job**		
	Mean	SD		Mean	SD
Control	2.28	0.48	Control	29	11.53
Tool	1.76	1.36	Tool	41	26.42
Instruction	1.92	0.85	Instruction	26	4.83
Both	1.65	0.42	Both	37	16.66

A two-way ANOVA (analysis of variance) with a 0.05 significance level (α) is carried out for the following dependent variables using Minitab (Release 12) statistical software:

- Number of risk factors identified
- Number of risk factors eliminated
- Lift Index
- Time to redesign the job

The data for number of risk factors identified and number of risk factors eliminated is treated as interval data rather than ordinal data. Equal intervals between the number of risk factors is assumed (e.g., the difference between 12 and 8 risk factors is equal to the difference between 8 and 4 risk factors). Data recorded for lift index is also interval data. The data for time to redesign the job follows a ratio scale since time has a true zero point. Since the data recorded for these dependent measures have at least interval properties, ANOVA (analysis of variance) can be applied.

Tables 4-7 show the summary ANOVA results. Table 4 is the ANOVA for number of risk factors identified.

TABLE 4. ANOVA for Risk Factors Identified

Source of variation	df	SS	MS	F	P
TOOL (A)	1	34.03	34.03	7.48	*0.011
INSTRUCTION (B)	1	75.03	75.03	16.49	*0.000
Interaction (AxB)	1	0.28	0.06	0.805	0.805
Error	28	127.38	4.55		
Total	31	236.72			

** indicates significance at p<0.05*

The results in Table 4 show that the subjects who received the tool (NIOSH lifting equation) and the subjects that received the instruction (ergonomics training) were able to identify significantly more risk factors than the controls ($p < 0.05$). There was no interaction effect. Figure 8 shows the graph of the average number of risk factors each group was able to identify in the original job.

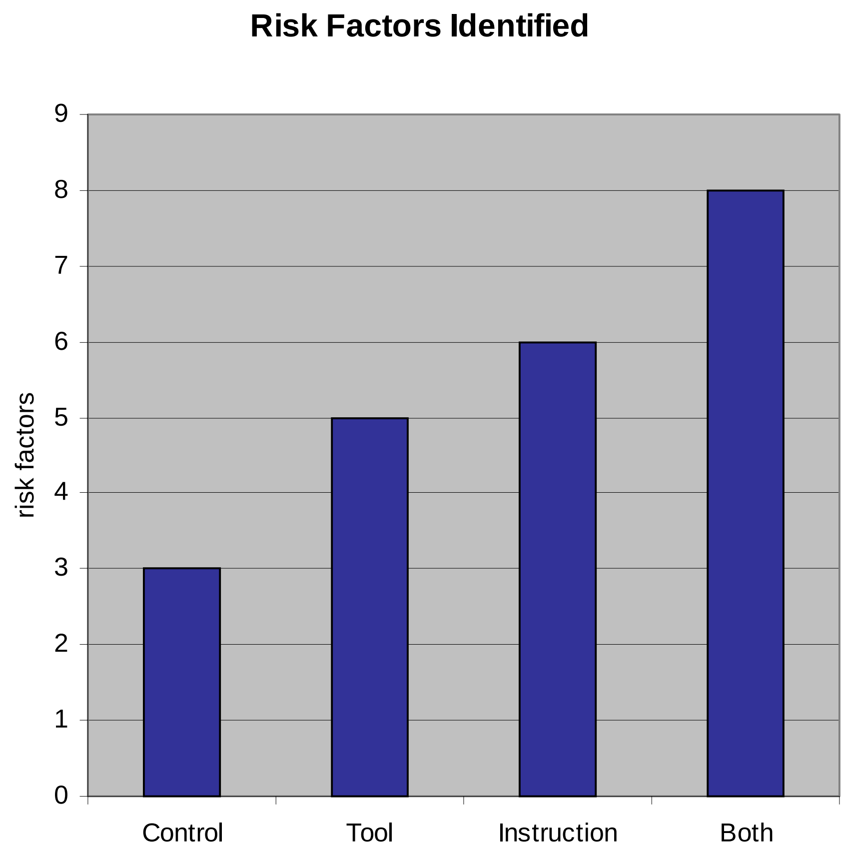

Figure 8. Average Number of Risk Factors Identified

The tool group (tool - no instruction) and the instruction group (instruction – no tool) were both significant effects. To show which of the significant results was the stronger effect, the percent variance is shown for the two significant components:

Omega squared is a measure of strength of association.

ω^2_{effect} = (variance estimate for the effect of interest) / (total variance estimate)

$\omega^2_{\alpha} = (SS_a - (p-1)(MS_{error})) / (SS_{total} + MS_{error})$

$\omega^2_{\alpha} = (34.03 - (1)(4.55)) / (236.72 + 4.55) = .1222$

So 12.22% of the total variance is estimated to be due to the main effect of factor A (TOOL).

$\omega^2_\beta = (SS_b - (q\text{-}1)(MS_{error})) / (SS_{total} + MS_{error})$

$\omega^2_\beta = (75.03 - (1)(4.55)) / (236.72 + 4.55) = .2921$

And 29.21% of the total variance is estimated to be due to the main effect of factor B (INSTRUCTION) and therefore the instruction is the stronger effect.

Table 5 shows the analysis of variance for number of risk factors eliminated.

TABLE 5. ANOVA for Risk Factors Eliminated

Source of variation	df	SS	MS	F	P
TOOL (A)	1	1.5	1.5	0.13	0.724
INSTRUCTION (B)	1	52.5	52.5	4.38	*0.046
Interaction (AxB)	1	0.8	0.8	0.07	0.800
Error	28	335.9	12.0		
Total	31	390.7			

** indicates significance at p<0.05*

The results show that the subjects who received the ergonomics instruction were able to eliminate significantly more risk factors than the other subjects ($p < 0.05$). The subjects who worked with the NIOSH lifting equation did not show significant results. Figure 9 displays the graph of the average number of risk factors each group was able to eliminate in their redesigns.

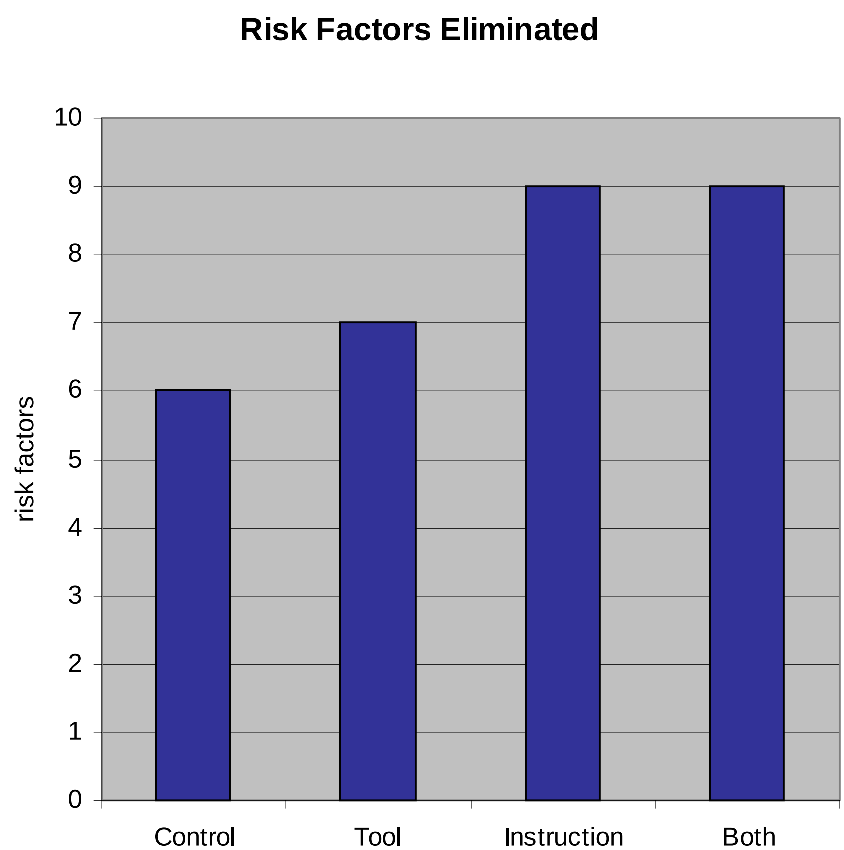

Figure 9. Average Number of Risk Factors Eliminated

Table 6 shows the results for lift index. Recall that the lift index is a measure of the safety of the lifting task. The lower the lift index, the safer the task.

TABLE 6. ANOVA for Lift Index

Source of variation	df	SS	MS	F	P
TOOL (A)	1	1.232	1.232	1.65	0.209
INSTRUCTION (B)	1	0.428	0.428	0.57	0.455
Interaction (AxB)	1	0.120	0.120	0.16	0.692
Error	28	20.910	0.747		
Total	31	22.690			

There were no significant results for lift index ($p > 0.05$).

Figure 10 shows a graph of the average lift index for each of the groups' redesigns of the lifting task part of the job. A lower lift index indicates a smaller risk for injury.

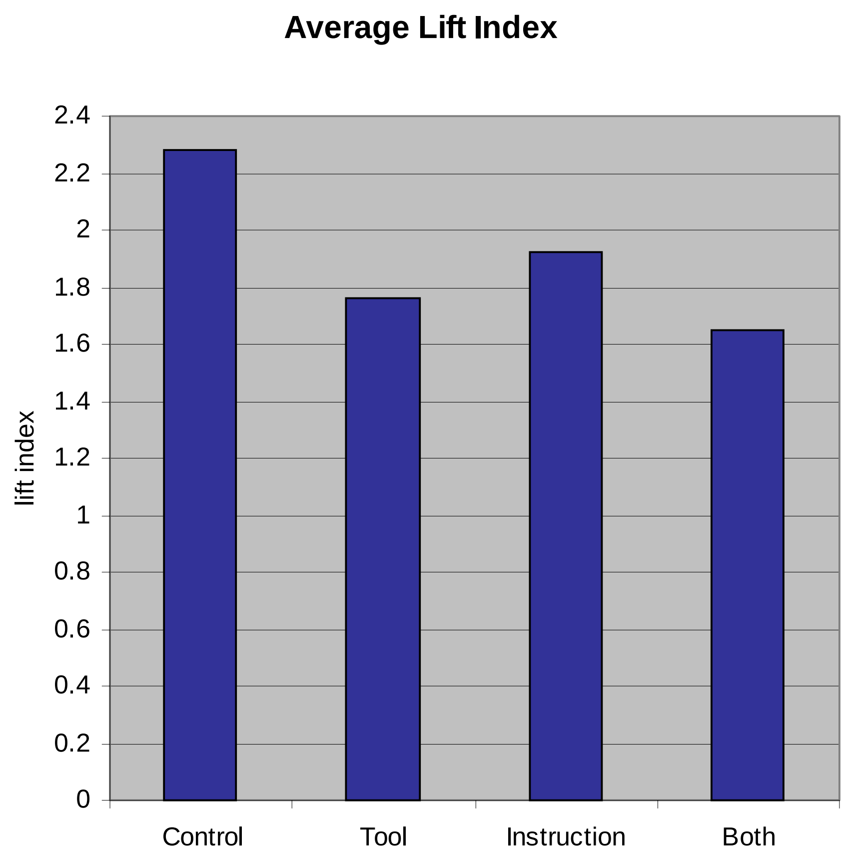

Figure 10. Average Lift Index

Table 7 shows the analysis of variance for time subjects used to redesign the job.

TABLE 7. ANOVA for Time to Redesign the Job

Source of variation	df	SS	MS	F	P
TOOL (A)	1	1070	1070	3.78	0.062
INSTRUCTION (B)	1	95	95	0.33	0.568
Interaction (AxB)	1	4	4	0.01	0.909
Error	28	7921	283		
Total	31	9089			

There were no significant results for time to redesign the job ($p > 0.05$).

Figure 11 displays the average amount of time (in minutes) that each group took to redesign the job.

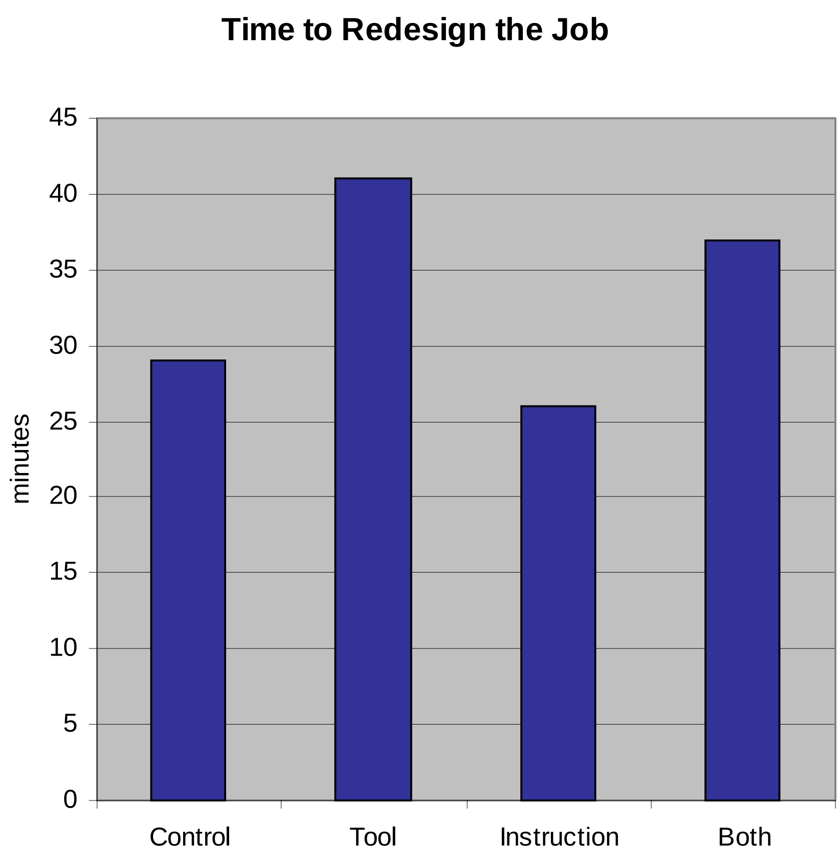

Figure 11. Average Time to Redesign the Job

The time to perform the original job and the time to perform the redesigned job were also measured and there are no significant differences in these. These two measures are not listed as dependent measures for this experiment but the non-significance of the results for these measures is noted for the curiosity of the reader.

Heart rate data. The raw heart rate data for each subject is listed in Appendix K. Each subject's heart rate was monitored throughout the experiment. Each subject's resting heart rate was first recorded. Then their heart rate was recorded while performing the original job, while redesigning the job, and while performing the redesigned job. Heart rate recorded during performance of the original job was compared to heart rate during performance of the redesigned job. Two-sample t-tests are used to discover if there is a significant reduction in heart rate while performing the redesigned task from the heart rate recorded during the performance of the original task. The following null and alternative hypotheses are used for all of the t-tests:

$Ho = \mu_1 - \mu_2 = 0$
$Ha = \mu_1 - \mu_2 > 0$

Where sample 1 is each subject's *percent change* in heart rate for the original job and sample 2 is each subject's *percent change* in heart rate for the redesigned job:

% change in heart rate for original job = [(original job heart rate – resting heart rate) / resting heart rate]x 100%.

% change in heart rate for redesigned job = [(redesigned job heart rate – resting heart rate) / resting heart rate]x 100%.

TABLE 8. T-test for the Control Group's Percent Change in Heart Rate

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	16.95543	10.12042912
Variance	55.10329	114.2951389
Observations	8	8
Pooled Variance	84.69921	
Hypothesized Mean Difference	0	
df	14	
t Stat	1.48535	
P(T<=t) one-tail	0.079809	
t Critical one-tail	1.761309	

Table 8 shows the t-test for the control group. The null hypothesis is not rejected ($p > 0.05$) and therefore the population means are assumed to be equal. In other words, there is no difference between subjects' heart rate while performing the original job and while performing the redesigned job. This result holds for the other three groups (tool, instruction, both) as shown in Tables 9, 10, and 11.

TABLE 9. T-test for the Tool Group's Percent Change in Heart Rate

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	14.60318	9.884891349
Variance	69.23572	44.26066542
Observations	8	8
Pooled Variance	56.74819	
Hypothesized Mean Difference	0	
df	14	
t Stat	1.252675	
P(T<=t) one-tail	0.115422	
t Critical one-tail	1.761309	

TABLE 10. T-test for the Instruction Group's Percent Change in Heart Rate

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	23.19682	19.6828301
Variance	75.89427	247.0425742
Observations	8	8
Pooled Variance	161.4684	
Hypothesized Mean Difference	0	
df	14	
t Stat	0.553078	
P(T<=t) one-tail	0.294467	
t Critical one-tail	1.761309	

TABLE 11. T-test for the Both (tool and instruction) Group's Percent Change in Heart Rate

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	22.93093	20.04010088
Variance	112.6483	138.2033696
Observations	8	8
Pooled Variance	125.4258	
Hypothesized Mean Difference	0	
df	14	
t Stat	0.516249	
P(T<=t) one-tail	0.306869	
t Critical one-tail	1.761309	

And finally, a t-test is used considering the entire sample of 32 subjects regardless of which condition(s) they received in Table 12:

TABLE 12. T-test for all 32 Subjects' Percent Change in Heart Rate

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	19.42159	14.93206
Variance	85.06793	147.9004
Observations	32	32
Pooled Variance	116.4842	
Hypothesized Mean Difference	0	
df	62	
t Stat	1.6639	
P(T<=t) one-tail	0.05059	
t Critical one-tail	1.669805	

Again, in this case, the null hypothesis is accepted ($p > 0.05$). The reduction in subjects' heart rate while performing the redesigned task is not significantly lower than while performing the redesigned task.

Heart rate variance was also analyzed. A significantly lower standard deviation is an indicator of more load. The raw data for standard deviation of heart rate appears in Appendix K. Paired t-tests were conducted to determine if standard deviation of heart rate while subjects performed the original job was significantly lower than while subjects performed the redesigned job. Paired t-tests are used since the different pairs are independent of one another (each subject has a different resting heart rate). The following null and alternative hypotheses are used for all of the paired t-tests:

$Ho = \mu_D = 0$
$Ha = \mu_D < 0$

Where D = X – Y is the difference between the first and second observations within a pair ($\mu_D = \mu_1 - \mu_2$). Sample 1 is each subject's standard deviation of heart rate for the original job and sample 2 is each subject's standard deviation of heart rate for the redesigned job. Tables 13-16 show the paired t-tests for each of the four groups.

TABLE 13. Paired T-test for Control Group's Standard Deviation of Heart Rate

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	7.988011	8.09937
Variance	2.99062	1.424995
Observations	8	8
Pearson Correlation	0.576345	
Hypothesized Mean Difference	0	
df	7	
t Stat	-0.22074	
P(T<=t) one-tail	0.415798	
t Critical one-tail	1.894578	

TABLE 14. Paired T-test for Tool Group's Standard Deviation of Heart Rate

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	7.118222	7.846155
Variance	1.477293	6.851104
Observations	8	8
Pearson Correlation	0.58289	
Hypothesized Mean Difference	0	
df	7	
t Stat	-0.95793	
P(T<=t) one-tail	0.185003	
t Critical one-tail	1.894578	

TABLE 15. Paired T-test for Instruction Group's Standard Deviation of Heart Rate

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	7.899319	8.891371
Variance	3.386606	3.18326
Observations	8	8
Pearson Correlation	0.448372	
Hypothesized Mean Difference	0	
df	7	
t Stat	-1.47365	
P(T<=t) one-tail	0.092034	
t Critical one-tail	1.894578	

TABLE 16. Paired T-test for Both (tool and instruction) Group's Standard Deviation of Heart Rate

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	7.453477	8.570427
Variance	2.026424	6.409135
Observations	8	8
Pearson Correlation	0.63309	
Hypothesized Mean Difference	0	
df	7	
t Stat	-1.60541	
P(T<=t) one-tail	0.07622	
t Critical one-tail	1.894578	

In all four groups, the null hypothesis is not rejected ($p > 0.05$). Standard deviation of heart rate while subjects performed the original job was not significantly lower then while subjects performed the redesigned job.

Qualitative Data Results

Questionnaire data. The raw questionnaire data is listed in Appendix J. A post-test questionnaire was given to each of the subjects (Appendix D). Each questionnaire featured a Likert rating scale. For a Likert rating scale, it is generally accepted that the data can be treated as ordinal or interval data. This experimenter prefers the more conservative approach and so the data is treated as ordinal and therefore non-parametric analysis is used. The Mann-Whitney procedure was used to analyze the questionnaire data. The Mann-Whitney procedure is the non-parametric counterpart of the independent 2-sample t-test. It uses a 2-sample rank test to compare two population medians.

After applying the Mann-Whitney procedure to the questionnaire data, one significant result is discovered for the following question:

I would have been able to develop a better redesign if I had been given a structured tool (e.g., a computer program) *for the analysis and redesign of the job.*

There was a significant difference in the median rating given by the subjects who received the ergonomics instruction as compared to the subjects who did not receive the ergonomics instruction as shown by the Mann-Whitney procedure in Table 17:

TABLE 17. Mann-Whitney Confidence Interval and Test

Q5 instruction given	N =	8	Median =	3.500
Q5 instruction not given	N =	8	Median =	2.000
Point estimate for ETA1-ETA2 is 1.000				
95.9 Percent CI for ETA1-ETA2 is (1.000,2.000)				
W = 93.0				
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.0101				
The test is significant at 0.0075 (adjusted for ties)				

The p-value is 0.0075 ($p < 0.05$) and so the subjects who received the instruction gave a significantly higher rating for this question on the Likert scale (1=strongly agree; 2=agree; 3=undecided; 4=disagree; 5=strongly disagree).

This result is confirmed by the Kolmogorov-Smirnov test. For between-subjects tests with ordinal data, the Kolmogorov-Smirnov test can be used when there are only two levels of a factor (whereas the Kruskal-Wallis ANOVA is used when there are three or more levels of a factor). The Kolmogorov-Smirnov procedure also tests for differences in the median ratings. Table 18 shows the Kolmogorov-Smirnov test for the data from the same question:

TABLE 18. Kolmogorov-Smirnov Test

Median Rating	Instruction Not Given, $S_8(X)$	Instruction Given, $S_8(Y)$
1	2	0
2	4	1
3	2	3
4	0	4
5	0	0
Total	8	8

Sample	1	2	3	4	5
$S_8(X)$	2/8	6/8	8/8	8/8	8/8
$S_8(Y)$	0/8	1/8	4/8	8/8	8/8
$S_8(X)-S_8(Y)$	0.250	0.625	0.500	0.000	0.000

$D^2_{8,8} = \{\max[S_8(X)-S_8(Y)]\}^2 = (0.625)^2$

$\chi 2 = 4D^2_{m,n}(mn/m+n) = [4(0.625)^2(8)(8)]/(8+8) = 6.25$

Tabled Value: $\chi 2 = 5.992$ (2df, $p<0.05$)

$6.25 > 5.992$

Significantly different median ratings ($p<0.05$)

The results of Kolmogorov-Smirnov test concur with the results of the Mann-Whitney test: There is a significant difference in the median rating given by the subjects who received the ergonomics instruction versus the subjects who did not receive the ergonomics instruction ($p < 0.05$).

Although this was the only statistically significant result from the Likert Scale rankings, the questionnaire data generally supports the quantitative results from the main dependent measures. This trend is discussed in Chapter 5 (Discussion).

Chapter 5. DISCUSSION

Validity of Hypotheses

The first three hypotheses concerned the lift index of the manual material handling task:

1. *The subjects who receive the ergonomics instruction will be able to redesign the original job with a significantly lower lift index than the control subjects.*

2. *The subjects who receive the NIOSH lifting equation will be able to redesign the original job with a significantly lower lift index than the control subjects. Furthermore, these subjects will be able to redesign the job with a lower lift index than the subjects who receive only the ergonomics instruction.*

3. *The interaction effects will not be significant. Furthermore, there will be no advantage to having both the instruction and the NIOSH lifting equation over just one of them with regards to the lift index.*

The first two hypotheses were supported in predicting the relative lift indexes between the groups. However, the differences were not found to be significant with an ANOVA ($p > 0.05$).

TABLE 19. Average Lift Index

Group	Ave Lift Index
Control	2.28
Tool	1.76
Instruction	1.92
Both	1.65

The third hypothesis was supported in predicting that there would be no interaction effect. The group that received the NIOSH lifting equation and the ergonomics instruction (“Both”) did design the lifting task with the lowest average lift index but the difference was not significant. Since there was no interaction effect (p>0.05), the results from the instruction were not dependent on the tool and vice versa. Table 19 shows the average lift index for each of the experimental groups' redesigns.

The next three hypotheses concerned the number of risk factors identified in the original job and the number of risk factors eliminated in the redesign. They were as follows:

4. *The subjects who receive the ergonomics instruction will be able to identify and eliminate significantly more risk factors during the analysis and redesign than the control subjects.*

5. *The subjects who receive the NIOSH lifting equation will be able to identify and eliminate significantly more risk factors during the analysis and redesign than the control subjects. Furthermore, these subjects will be able to identify and eliminate more risk factors that the subjects who receive only the ergonomics instruction.*

6. *The interaction effects will not be significant. Furthermore, there will be no advantage to having both the instruction and the NIOSH lifting equation over just one of them with regard to identifying and eliminating risk factors.*

The fourth hypothesis was supported. Two ANOVAs show that the subjects who received the ergonomics instruction were able to identify *and* eliminate significantly more risk factors (Tables 3 and 4 from the previous chapter). The fifth hypothesis, however, was only partially supported. The subjects who used the NIOSH lifting equation were able to identify significantly more risk factors than the control subjects but the number of risk factors that they eliminated in the redesign was *not* significantly different (Tables 3 and 4). Furthermore, hypothesis 5 predicted that the subjects who used the NIOSH lifting equation would be able to identify and eliminate more risk factors than the subjects who received the ergonomics instruction. In fact, it was the opposite that occurred; the subjects who received the ergonomics instruction performed better with respect to these two measures. Table 20 shows the averages.

TABLE 20. Average Risk Factors Identified and Eliminated

Group	Risk Factors Identified	Risk Factors Eliminated
Control	3	6
Tool	5	7
Instruction	6	9
Both	8	9

The "Tool" group (NIOSH lifting equation) and the "Instruction" group (ergonomics training) were both able to identify significantly more risk factors than the control group (Table 4). "Instruction" was the stronger (strength of association) of the two significant effects. Recall from pages 46 and 47 that 12.22% of the total variance is estimated to be due to the main effect of factor A (Tool) and 29.21% of the total variance is estimated to be due to the main effect of factor B (Instruction). The subjects who received ergonomics instruction, therefore, performed the best with respect to identifying risk factors in the original job. Likewise, the subjects who received the ergonomics instruction were the only ones to show a statistically significant reduction of risk factors in the redesign (Table 5).

The sixth hypothesis was supported. There were no interaction effects for these measures ($p>0.05$). Also, there was no advantage to having both the instruction and the NIOSH lifting equation over just one of them with regard to identifying and eliminating risk factors. The potential benefits of having both the instruction and the tool can be inferred by adding the benefits of the two independently since there were no interaction effects. The tool by itself was shown to be largely ineffective. The favorable results from the instruction-tool subjects ("both" subjects) were due mostly from the instruction. This suggests that the subjects who received the ergonomics instruction *and* used the NIOSH lifting equation did not have an advantage over the subjects who just received the ergonomics instruction.

The final hypothesis concerned satisfaction ratings:

7. *Subjects who receive the ergonomics instruction and/or the NIOSH lifting equation will give a higher average satisfaction rating for performing the redesigned job with respect to performing the original job than the average satisfaction rating given by the control group. However, there will be little differences amongst the average satisfaction ratings given by the experimental groups.*

Table 21 shows the median satisfaction ratings. The data is from question #2 on the questionnaire: "I prefer performing the redesigned job rather than the original job".

TABLE 21. Median Satisfaction Ratings for Performing the Redesigned vs. Original Job

Group	Ave Median Rating
Control	1
Tool	1
Instruction	1
Both	1

(1=strongly agree, 2=agree, 3=undecided, 4=disagree, 5=strongly disagree)

All groups gave a "strongly agree" rating for this question. The control group was just as satisfied with their redesigns as the others.

Time to Redesign the Job

Although analysis of variance showed no significant differences between the groups for time to redesign the job (Table 7), subjects who used the NIOSH lifting equation appear to have taken longer to redesign the job than those who did not (Figure 11). This statistical trend is supported by the ANOVA shown in Table 7. The p-value for the subjects who received the NIOSH lifting equation (tool condition) was 0.062 which is very close to being significant at alpha = 0.05 and would have been significant with a less conservative alpha (e.g., α=0.10). The Tool subjects, who received only the NIOSH lifting equation, redesigned the job in an average of 41minutes and the subjects who received both conditions redesigned the job in an average of 37 minutes. Conversely, the two groups who did not receive the NIOSH lifting equation, instruction group and control group, redesigned the job in an average of 26 minutes and 29 minutes respectively. This trend suggests that using the tool to assist in the analysis and redesign of the job is more time consuming than not using it. This conclusion implies that a tradeoff exists between the potential benefits of using the tool and the added time involved in applying it.

Perception of Task Realism

When asked to rate a response for "The original task was a realistic task (one that may actually be performed in industry)", median response of the 32 subjects was 1 (=strongly agree). This result implies a good indicator of face validity. In other words, the subjects believed that the job set-up in the laboratory was a good representation of a real industrial-type job.

Postural Discomfort

One of the dependent measures was postural discomfort. This data was collected with the Likert–scale questionnaire. Subjects were asked to rate a response for, "I experienced more postural discomfort while performing the original job than when performing the redesigned job." There were no significant differences in the median ratings for each group. The average median rating for each group was between 1 and 2 (1=strongly agree, 2=agree).

Discussion of Heart Rate Results

The purpose of recording subjects' heart rate throughout the experiment was twofold. First, heart rate data from performing the original task was to be compared to that of the redesigned task in hope of determining which of the tasks is more difficult to perform physically. Second, heart rate was also recorded during the redesign phase to see if any insight can be gained about the mental workload for the task of redesigning the job.

No significant results were found with the heart rate data. As for the first goal, heart rate was less when performing the redesigned job with respect to the original job for all of the groups. These differences, however, were not statistically significant (Tables 8-12, previous chapter). Furthermore, the were no significant differences in standard deviation of heart rate for all four groups between performing the original job and the redesigned job.

Although the differences in heart rate between performing the original and redesigned jobs were not significant, the trend for each of the subjects to show a lower heart rate while performing the redesigned job should be noted. In fact, 26 of the 32 subjects' heart rate was lower while performing the redesigned job than while performing the original job. Table 12 shows the T-test for all 32 subjects' percent change in heart rate (from their resting heart rate). The test just barely failed to detect a significant difference for subjects' percent change in heart rate between performing the two jobs ($p=0.051$, $\alpha=0.05$). However, the statistical trend suggests that in general, the subjects' redesigns were easier to perform (less workload) than the original job.

The second goal for recording heart rate was to see if any insight could be gained about the mental workload of the redesign task by comparing the subjects' heart rate during the redesign phase with the their resting heart rate. No insight can be gained for the second goal because of confounding factors explained below.

Many subjects' resting heart rate was unusually high and inconsistent between groups. Before performing the original task, each subject's resting heart rate was recorded for a few minutes. In hindsight, some subjects may have had aroused heart rates from biking to the experiment, jogging up the stairs of the building, or drinking coffee. These factors ultimately may have contributed an inaccurate resting heart reading.

To illustrate the inconsistency of the resting heart rate between the groups, Table 22 shows an ANOVA using the *% change in heart rate* of subjects' heart rate recorded during the performance of the original job and their resting heart rate.

TABLE 22. ANOVA for % Change in Heart Rate while Performing the Original Job

Source of variation	df	SS	MS	F	P
TOOL (A)	1	13.5	13.5	0.17	0.680
INSTRUCTION (B)	1	423.4	423.4	5.43	*0.027
Interaction (AxB)	1	8.8	8.8	0.11	0.739
Error	28	2185.1	78.0		
Total	31	2630.8			

** indicates significance at p<0.05*

Since *all* of the subjects performed the exact same original job, there should be no significant differences between the % change in heart rate. But in fact, the subjects who received the instruction showed a significantly higher % change in heart rate ($p < 0.05$). This is because their resting heart rate was much lower than the other subjects. One possible explanation for this discrepancy is that the subjects who received the ergonomics instruction were not affected by the confounding factors (biking to the experiment, drinking coffee, etc.) because they had to sit through a 20 minute ergonomics presentation before their resting heart rate was recorded. This 20 minute delay may have given their heart rate a chance to approach the true resting heart rate level. Figure 12 shows each group's average percent change in heart rate (from the resting heart rate) while performing the original job.

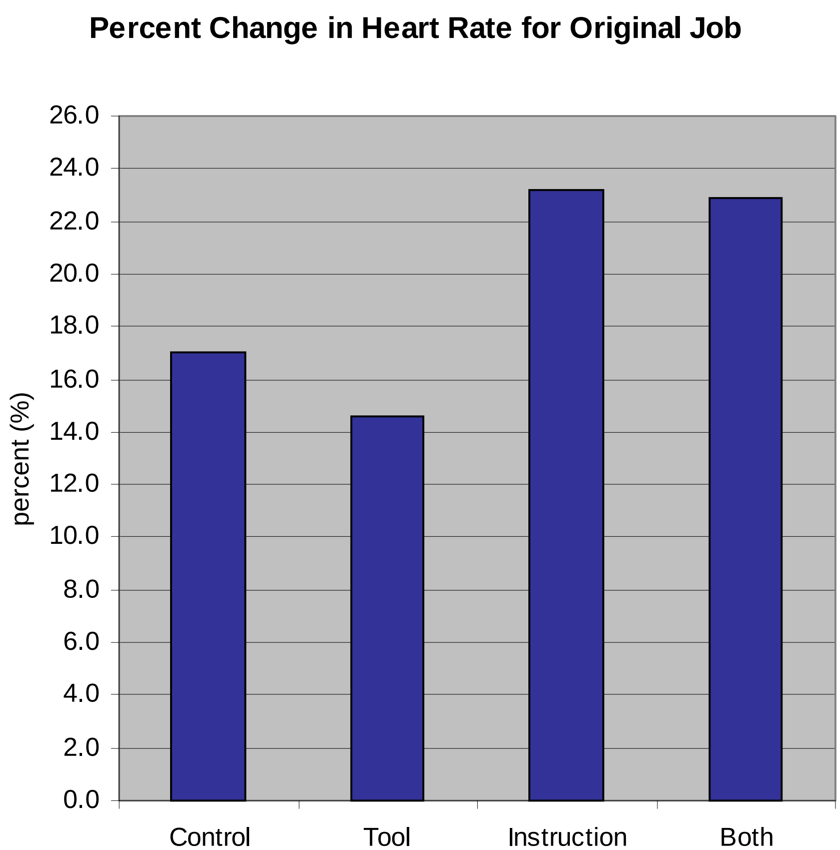

Figure 12. Percent Change in Heart Rate while Performing the Original Job

The abnormally high resting heart rate readings are apparent when comparing subjects' resting heart rate with their heart rate during the redesign phase of the experiment. For 75% of the subjects, the heart rate recorded during the redesign phase was *less* than their resting heart rate.

Finally, for the safety of the subjects, the boxes were empty during the performance of the original and redesigned lifting task. Subjects were to assume that each of the boxes weighed 22lbs. This safety measure was necessary since the original lifting task was designed to be risky. But the safety of having empty boxes was a tradeoff with task realism. The heart rate data is recorded for the subjects performing the experiment with empty boxes and thus is not really representative of what the heart rate data would be in an industrial setting.

For all of the reasons discussed in this section, nothing conclusive can be interpreted from the heart rate data.

Instruction Subjects

The ergonomics instruction was the most effective experimental condition. The subjects who received the ergonomics instruction were able to identify significantly more risk factors in the original job and eliminate significantly more risk factors in the redesign. Since a reduction in the number of risk factors is an effective method for measuring the success of a PE approach (Buckle and Li, 1996; Cohen, 1994), providing the participants with basic ergonomics training was the most successful technique for this participatory approach to redesign. The subjects that received the ergonomics instruction did not score significant results with respect to the other subjects for the lift index of the manual material handling task. However, these subjects redesigned the task with an average lift index of 1.92 from the original task lift index of 3.57.

Figure 13 shows the redesign of one of the instruction subjects (Subject 11).

Figure 13. An Example Redesign from an Instruction Subject

Subject 11's redesign is representative of the types of designs this group of subjects developed. The subject moved the black adjustable shelving system pictured in Figure 13 so that it is positioned parallel to the computer workstation. The subject added two middle shelves to place the shipment of boxes. The new position of the shelves allows the subject to place the boxes without having to reach too high and with minimal amount of twist. The subject also added a chair to the workstation (there was no chair in the original design). Also, the subject moved the desk lamp up one shelf from its original location thereby eliminating glare in the eyes while lifting the boxes and glare on the computer screen. While lifting the boxes, the subject used a squat lift rather than a stoop lift to maintain a straight back. The subject eliminated 13 of the 16 overall risk factors that were present in the original design. For example, by simply adding a chair to the workstation, the subject provided a change of posture for the job (alternating between sitting and standing) and improved the height of the computer monitor and keyboard.

Tool Subjects

Although the purpose of NIOSH lifting equation is to analyze and redesign lifting tasks, the subjects who used it were not able to redesign the lifting task with a significantly lower lift index than the other subjects. The "tool" subjects redesigned the lifting task with an average lift index of 1.76. While this lift index was lower (and thus better) than the average lift index of the control subjects and the instruction subjects (Table 19), it was not significantly better.

This result is surprising since the tool subjects were actually able to use the NIOSH lifting equation to measure the lift index of the task themselves, knowing that a lift index < 1.00 was the ideal. Many of the tool subjects had a redesign in mind and validating their redesign with the NIOSH lifting equation was often an afterthought. From informal discussion with the participants after the experiment, some of the subjects simply did not feel that using the NIOSH lifting equation was necessary. For example, when asked to rate, "The NIOSH lifting equation was helpful to analyze and redesign the job", subject 26 gave a response of 4 (=disagree). Subject 26 only used the lifting equation because it was a requirement. However, the use of the equation probably had little or no impact on the redesign. Ironically, of all subjects, including the two experts, it was subject 26 who scored the best lift index (0.00). Subject 26 simply designed the lifting task out of the job. This subject decided to push the boxes off of the dolly onto a shelf at ground level with his foot, thus making lifting any boxes unnecessary.

The tool subjects were able to identify significantly more risk factors than the control subjects. However they did not eliminate significantly more risk factors in their redesigns. After learning the equation, the subjects were aware of the parameters of a lifting task and this helped them to identify risk factors since many of the risk factors were related to the lifting task itself. The tool subjects, however, did not eliminate significantly more risk factors than the control subjects. This suggests that the NIOSH lifting equation alone is not as effective as the ergonomics instruction in eliminating risk factors. The subjects who received ergonomics instruction were better prepared to identify and eliminate risk factors. The ergonomics instruction gave an overview of the good workplace design whereas the NIOSH lifting equation concentrated on the lifting task exclusively.

Figure 14 shows a redesign that one of the tool subjects implemented (subject 10).

Figure 14. An Example Redesign from a Tool Subject

In this case, the subject used the NIOSH lifting equation effectively to find the ideal height at which to place the boxes (30”). The subject lowered the top shelf of the black adjustable shelving system to 30” above the ground.   The subject moved the tan shelves adjacent to the black shelves and used the top tan shelf to place the rest of the boxes (also 30” from the ground). The subject eliminated the step (sharp change in floor level) by providing a ramp so that the dolly with the box could be rolled right up the shelves. The ramp idea was a pencil and paper one because it could not be physically implemented. However, the subject is still given credit for the ramp. The subject redesigned the lifting task such that the lift index is 0.65 which is ideal (an index <1.00 is considered safe).

Instruction-Tool Subjects

The subjects who received the ergonomics instruction and the NIOSH lifting equation ("both" subjects) redesigned the lifting task with the lowest lift index (1.65), identified the most risk factors in the original job (8) and tied the instruction subjects for eliminating the most risk factors in the redesign (9). However, analysis of variance showed that these results are not significantly better than the corresponding results for the subjects who received only the ergonomics instruction. Since there were no interaction effects for these measures ($p>0.05$), the potential benefits of having both the instruction and the tool can be inferred by adding the benefits of the two independently. The tool by itself was shown to be largely ineffective. The favorable results from the instruction-tool subjects ("both" subjects) were due mostly from the instruction. This suggests that the subjects who received the ergonomics instruction *and* used the NIOSH lifting equation did not have an advantage over the subjects who just received the ergonomics instruction.

When asked to rate "Learning and using the NIOSH lifting equation to analyze and redesign the job was more helpful than the ergonomics instruction", these subjects gave a median rating of 3 (=undecided). However, then subjects gave more favorable rating for the ergonomics instruction over the NIOSH lifting equation for other questions. When asked to rate the effectiveness of the ergonomics instruction and the NIOSH lifting equation separately in helping them identify risk factors, the subjects gave a median rating of 1.5 for the instruction and 2 for the NIOSH lifting equation (1=strongly agree, 2=agree). For helping them eliminate risk factors, subjects gave the same median ratings of 1.5 for the instruction and 2 for the NIOSH lifting equation. This result suggests that the subjects who received both the instruction and the NIOSH lifting equation preferred the instruction.

Figure 15 shows an example of a redesign from one of the instruction-tool subjects (subject 13).

Figure 15. An Example Redesign from an Instruction-Tool Subject

The subject in this case decided to use the non-adjustable shelves pictured in Figure 15 to place the boxes on. The subject chose to load two boxes at a time on the dolly to transport them. The desk lamp was turned off to eliminate glare and a chair was added at the computer workstation.

Instruction vs. Tool

The subjects who were most successful in identifying/eliminating risk factors and designing the lifting task with the lowest lift index were those who received the ergonomics instruction and the NIOSH lifting equation. The analysis of variance, however, did not show that they were significantly more successful that the subjects who just received the instruction. Furthermore, the analysis of variance showed the NIOSH lifting equation to be largely ineffective in this case. Therefore, the group that received the ergonomics instruction performed optimally relative to the other groups. The instruction group performed optimally because they performed statistically as well as the group that received the instruction *and* the tool but did not need to waste time/effort to learn how to use and apply the NIOSH lifting equation. The one question from the Likert-scale rankings that produced statistically significant results supports this conclusion. Subjects were asked to rank a response for:

I would have been able to develop a better redesign if I had been given a structured tool (e.g., a computer program) *for the analysis and redesign of the job.*

Recall from Tables 16 and 17 that the subjects who received the instruction gave a significantly higher rating for this question on the Likert scale ($p < 0.05$). The subjects who received the ergonomics instruction gave a median rating of 3.5 (3 = undecided, 4= disagree) whereas the subjects who did not receive the ergonomics instruction gave a median rating of 2 (=agree). The subjects who did not receive the instruction agreed that using a tool would have enabled them to produce a better redesign. However, the subjects who received the instruction felt that also using a structured tool (e.g. the NIOSH lifting equation) would not have enabled them to produce a better redesign than if they had just received the ergonomics instruction. The instruction subjects' confidence in the ergonomics instruction supports that conclusion the instruction group was the optimal group over the instruction-tool group.

Experts

The two experts performed as expected. The experts identified an average of 8 risk factors in the original job and eliminated an average of 11 risk factors in their redesign. The group that received the instruction and the NIOSH lifting equation ("both" subjects) were also able to identify an average of 8 risk factors. None of the experimental groups, however, were able to eliminate as many risk factors in the redesign as the experts. Also, only the experts were able to redesign the lifting task with the ideal lift index of < 1. The experts' average lift index was 0.86.

Figure 16 shows the redesign of one of the experts (expert 2).

Figure 16. An Example Redesign from one of the Experts

The expert moved the black adjustable shelving system directly in front of the unloading area and adjusted the shelves for better access. The expert used a push-cart to transport the boxes rather than the dolly. The push-cart enables the participant to unload the boxes without having to bend over to pick the box up from ground level as when using the dolly. The expert was able to place the boxes on the shelves with ease. As shown in Figure 16, there is very little horizontal and vertical travel distance from the origin of the lift (the push-cart) to the destination of the lift (the shelves).

Participation vs. Non-participation

The experts' data is meant to represent the case where management has implemented a redesign of the job without participation from their own workers. It is assumed that the redesign implemented by management would have been developed by their own ergonomists or by consultants with similar knowledge to that of the graduate students who served as experts for this study. The experts' data is compared against the data from the regular subjects. By comparing the time to redesign, quality of the redesign, and satisfaction, insight can be gained on the potential benefit of the participation itself.

The instruction group performed optimally with respect to the other experimental groups and therefore is chosen as the representative group to compare to the experts. Table 23 shows the instruction subjects' average performance with the experts'.

TABLE 23. Instruction Group vs. Experts

	Instruction Subjects	Experts
Risk Factors Identified	6	8
Risk Factors Eliminated	9	11
Lift Index (LI)	1.92	0.86
Time to Redesign	26 min	51 min

The quality of the instruction subjects' redesigns are comparable to the experts' with respect to risk factors identified and risk factors eliminated. For lift index, however, the experts redesigned the lifting task with a lift index < 1 which is the ideal. The instruction subjects were not able to design with a lift index < 1. Indeed, none of the experimental groups were able to do this. A lifting task lift index > 1 may put the worker at an increased risk for injury. Interestingly, the instruction subjects only took an average of

26 minutes to redesign the job whereas the two experts took an average of 51 minutes. The 51 minutes may not necessarily be representative since there were only two experts. The two experts, however, were much more meticulous during the redesign phase of the experiment than the instruction subjects. There is, therefore, a tradeoff between speed and quality. The instruction subjects redesigned the job faster than the experts but the quality of their redesigns is not as good as the experts' redesigns.

Translating this information into the real world, it would seem that participation is beneficial, feasible, and therefore better than not participating at all. The subjects showed that they were capable of redesigning the job well with respect to identifying and eliminating risk factors. However, the subjects' poor performance with designing the lifting task with an acceptable lift index suggests that an expert is needed to ensure that any lifting tasks are "safe" by NIOSH standards ($LI < 1$). Lost work time due to workers' participation should not be a consideration since the subjects took half as long as the experts to redesign the job, assuming the experts are paid more than the front-line workers. Furthermore, the subjects' satisfaction rating were high. When asked to rate "I would have preferred just being told what to do for the redesign rather than redesigning the job myself", the 32 subjects gave a median rating of 4 (=disagree). The instruction group by themselves also gave a median rating of 4.

Group vs. Individual

In participatory ergonomics, participation is usually performed in a group. Subjects in this experiment, however, analyzed and redesigned the job as individuals. Using group redesign in this experiment was not feasible since the number of subjects needed would have to be multiplied by the current number of subjects (e.g., for groups of 4, 128 subjects would be needed – 32x4=128). Also, since manual lifting tasks are usually done by one worker, redesigning the job on an individual basis was assumed acceptable. Previous research, however, has established that groups make better decisions than individuals (e.g., Holloman and Hendrick, 1971).

Exploratory data was collected for group redesign. Each subject rated, “I would have preferred redesigning the job in a group rather than by myself.” The average median rating for all 32 subjects was 3 (=undecided). Subjects did not seem to have a preference for group or individual design.

Each subject was asked the open-ended question, “What would have been different if you were redesigning the job in a group rather than by yourself?”. Subjects generally agreed on the trade-off that the quality of the redesign would be better but that the redesign process would be longer. Many subjects also noted that for group design, everyone’s physical differences would have to be considered for the redesign rather than customizing the job to best fit their individual needs.

Limitations

There are several limitations associated with this study. The first involves the subject pool. The subject pool is meant to represent workers who would actually perform the manual lifting tasks in industry. Subjects are selected from a student population and are meant to reflect the likely users (representative participation). Since the subjects do not perform the experimental tasks in real life, the realism of the experiment is limited.

In participatory ergonomics, participation is usually done in a group. Subjects in this experiment, however, analyzed and redesigned the job as individuals. Using group redesign in this experiment was not feasible since the number of subjects needed would have had to have been multiplied by the current number of subjects (e.g., for groups of 4, 128 subjects would be needed – 32x4=128). Since manual lifting tasks are usually done by one worker, redesigning the experimental tasks on an individual basis is deemed acceptable. Previous research, however, has established that groups make better decisions than individuals (e.g., Holloman and Hendrick, 1971). Therefore, the individual redesign that this experiment was constrained to is a limitation.

Industrial workers have much experience in performing the manual material handling jobs for which they are responsible. The subjects in this experiment, on the other hand, redesigned a job that they have only briefly performed. Furthermore, since the experimental manual material handling job is constructed in the lab and is meant to simulate a real industrial task, the realism of the task may also be considered a limitation. The subjects are told to assume that each of the boxes weighs 22 lbs (10 kg). However, each of the boxes are empty to ensure the safety of the subjects since to lifting task was designed to be risky. If the boxes actually weighted 22 lbs, the subjects would be at risk for injury according to NIOSH standards. Unfortunately, the empty boxes also limit the realism of the experimental job.

Chapter 6. CONCLUSION

Summary

The results of this study help shape the optimal relationship between the worker and the ergonomist (expert) in a participatory ergonomics approach for the redesign of an industrial-type job. The subjects who received the ergonomics instruction performed optimally with respect to the other groups. Subjects who received ergonomics training showed that they were capable of redesigning the job well with respect to identifying and eliminating risk factors. The instruction subjects identified significantly more risk factors in the original job and eliminated significantly more risk factors in the redesign than the control subjects ($p < 0.05$). Furthermore, when asked on the post-test questionnaire, the subjects preferred the idea of being involved in the redesign of the job rather than just being told what to. However, since ergonomics training was identified as a requisite for a successful PE approach, an ergonomist/expert is needed at the beginning of the process to provide ergonomics training to the workers. Also, an ergonomist/expert is needed at the end of the participatory process. Subjects were not able to redesign the lifting task with a lift index that corresponds to an acceptable level of safety. Therefore, and ergonomist/expert is needed to validate and check the feasibility of the redesign and to ensure the safety of any lifting tasks.

A Suggested PE Approach for Redesigning Manual Material Handling Jobs

Ergonomics instruction should be a requisite for any PE approach. Subjects who received just very basic ergonomics training on the basics of workplace design and manual lifting were able to identify and eliminate significantly more risk factors than those who did not receive ergonomics instruction. Devereux (1998) documented a case study in which ergonomics training was not provided to the workers. The redesigned tool in this case study showed few benefits and was shown to possibly increase physical strain. Likewise, in the experiment conducted for this study, control subjects redesigned the job with few benefits. At least basic ergonomics instruction relevant to the job or task being redesigned is a necessity. Furthermore, the workers should be tested for how much knowledge they have acquired after the ergonomics training to ensure that they have reached a minimum level of proficiency.

Experts or ergonomists are needed to validate the redesign and to check the safety of any manual material handling. One approach that is currently used has an expert validate or check the feasibility of the redesign at the end of the participatory process (e.g., Vink et al., 1992) as opposed to having an expert be involved in all of the procedures. In this experiment, none of the experimental groups redesigned the lifting task with a “safe” lift index. An expert, therefore, is needed ensure the safety of any manual material handling. The subjects who received the ergonomics training did demonstrate that they were capable of identifying and eliminating risk factors in the job. Therefore, having the expert involved in all of the procedures is not necessary. Rather, the expert is needed at the beginning of the process to provide the ergonomics training to the participants and at the end of the process to validate the redesign. The workers should, however, be informed as to what the expert will be doing and why so that they will not feel that their work is being undermined.

The NIOSH lifting equation was not a popular or effective tool for the participants, who had no prior ergonomics experience. That is not to say, however, that the NIOSH lifting equation is not a good or effective tool in general. The NIOSH lifting equation should be used by those with adequate ergonomics experience. In the case of lifting tasks, the expert can use the NIOSH lifting equation to check the safety of the tasks.

The size of the participatory group should be a consideration. This thesis did not address the size of a participatory group. Previous research has shown that a group size of approximately 6 is optimal in terms of quality of decisions and economy (Holloman and Hendrick, 1971). The experimental job in this experiment was redesigned on an individual basis. Exploratory questionnaire data on group redesign showed that the subjects themselves did not have a preference for participating in a group or as individuals. The size of the participatory group should be based on the objective of the PE approach. If an entire process is being redesigned, then the group should consist of all those involved in the process or at least be adequately represented if there are many persons involved in the process.

Finally, any PE approach should be well defined according to the dimensions of PE given by Wilson and Haines (Wilson and Haines, 1997; Haines and Wilson; 1998). Although a unifying model for PE does not exist because of its broad practice, any PE approach can be defined by its focus, purpose, timeline, involvement, coupling, and requirements. For example, the PE approach used in this thesis experiment can be defined by these dimensions. The *level* of this study was on the micro-level with the *focus* being on the redesign of a manual material handling job. The *timeline* was a discrete one. *Involvement* was representative, with subjects selected from a student population so as to reflect the likely users. The participative methods were *directly coupled*; the participants redesigned the job with no filtering of their recommendations. Finally, the participation was *voluntary*.

Future Research

There are many anecdotal case studies that describe successful participatory ergonomics approaches. Since these studies did not involve controlled laboratory experiments, changes in the measures that were used to measure success cannot be attributed directly to the interventions undertaken with any certainty (e.g., van der Molen et al., 1993; Halpern and Dawson, 1997; Moore and Garg, 1997). In this controlled experiment, the use of ergonomics training for the participants was shown to be necessary for a PE approach involving the redesign of a manual material handling job. The NIOSH lifting equation was shown to be an inappropriate PE tool for participants to use who do not have proper ergonomics experience and as a result, the use of an expert is needed to validate a design. This experiment, however, addressed a very specific and narrow application area of participatory ergonomics. PE means different things to different people and is being used for design, redesign, and implementation of tasks, jobs, processes, products, technology, and organizations in a large variety of work settings.

Future research should design experiments involving these other application areas of PE. Also, future experimentation should explore the apparent tradeoff for speed and quality between the participants and the experts. Exploratory data from this study showed that the participants redesigned the job in half the time that the experts used to redesign. The experts' redesigns, however, were of greater quality. An interesting research question would address what may happen if the participants were trained to slow down to match the experts' time to redesign. Can the participants be trained to perform as well as the experts?

There is certainly a need for future research. Further controlled experimentation and systematic studies can help in the development and validation of new PE tools and techniques. Also, future research is needed to develop theoretical framework for PE and to provide some guidance for its implementation and use in organizations.

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LIST OF APPENDICES

APPENDIX A1.

Specifications of the lifting task and boxes

Weight of boxes: 22 lbs each

Dimensions of boxes: 12” x 12” x 12” each

Horizontal hand location at origin: 25”
(horizontal distance of the hands from the midpoint between the ankles measured at the origin of the lift)

Vertical hand location at origin: 0”
(vertical distance of the hands from the floor measured at the origin of the lift)

Horizontal hand location at destination: 25”
(horizontal distance of the hands from the midpoint between the ankles measured at the destination of the lift)

Vertical hand location at destination: 74”
(vertical distance of the hands from the floor measured at the destination of the lift)

Asymmetric angle at origin: 90 degrees
(angular displacement of the load from the sagittal plane measured at the origin of the lift)

Asymmetric angle at destination: 90 degrees
(angular displacement of the load from the sagittal plane measured at the destination of the lift)

Frequency rate (lifts/minute): 1

Duration: 8 hours

Object coupling: Fair (as defined by NIOSH)

RWL (origin) = 6.77 lbs

RWL (destination) = 6.16 lbs

Lift index (origin): 3.25

Lift index (destination): 3.57

APPENDIX A2.

Inventory form

INVENTORY FORM FOR STORAGE OF BOXES

SHIPMENT 1**

Arrival date:

Origin:

Number of boxes:

Identification code:

Description of contents:

SHIPMENT 2**

Arrival date:

Origin:

Number of boxes:

Identification code:

Description of contents:

SHIPMENT 3**

Arrival date:

Origin:

Number of boxes:

Identification code:

Description of contents:

APPENDIX A3.

Instructions for identifying risk factors

Please list as many risk factors that you can identify for the job you just performed. A risk factor is something about the job that can cause discomfort and may eventually lead to injury. List risk factors for *any* part of the job. Risk factors generally concern the design of the workplace, and the design of the tasks in the workplace. Examples of risk factors could be:

- The weight of a object is too heavy (for lifting)
- Object has sharp edges and is difficult to grasp
- Difficulty placing an object where it is supposed to go
- The floor is slippery
- Computer screen is causing eye strain
- Not enough leg space while sitting at a workstation
- Too much noise in the environment

<u>List risk factors</u>:

APPENDIX A4.

Instructions for redesigning the experimental job

Please redesign the job that you have just performed in the interest of making it "safer" by trying to eliminate any risk factors that you have identified. For example, you may move an object if it is moveable or adjust a shelf if it is adjustable. Please list any changes you make to the original design on this sheet. If you have any ideas for redesign that you cannot physically implement, also list them on this sheet. You do not have to limit yourself to the lifting task. You may change anything about any part of the job. If you think of additional risk factors that you did not already list on the previous sheet, you may go back to that sheet and list them.

APPENDIX B

Ergonomics Instruction for the Participants

The instructional content is derived from NIOSH (1981), Kennedy et al. (1996), and Chaffin et al., p. 511 (1999) and follows this outline:

Basic Ergonomics Instruction for Workplace Design and Manual Lifting

Occupational biomechanics defined

Maintain the demands of the task less than the capabilities of the human (D<C)

Ergonomics – Design Principles

- Keep objects within easy reach
- Proper heights
- Excessive force
- Good posture
- Excessive repetition
- Fatigue
- Direct pressure
- Adjustability
- Change of posture
- Clearance and access
- A comfortable environment
- Work organization
- Clarity and understanding

Manual Lifting

- The risks to health of unskilled lifting
- The basic biomechanics of lifting
- Handling skill
- How to avoid the unexpected
- Handling aids

APPENDIX C

NIOSH Lifting Equation and Associated Tables

The following information is from Waters et al. (1993).

Lifting equation:
RWL = LC x HM x VM x DM x AM x FM x CM

RWL = recommended weight limit

	Metric	*US customary*
LC = load constant	= 23 kg	= 51 lbs
HM = horizontal multiplier	= (25/H)	= (10/H)
VM = vertical multiplier	= (1 – (0.003 x |V – 75|)	= (1 – (0.0075 x |V – 30|)
DM = distance multiplier	= (0.82 + (4.5/D))	= (0.82 + (1.8/D))
AM = asymmetric multiplier	= (1 – (0.0032 x |A|))	= (1 – (0.0032 x |A|))

FM = frequency multiplier (from Table C2)
CM = coupling multiplier (from Table C1)

H = horizontal distance of the hands from the midpoint between the ankles. This must be measured at the origin (H_0) and the destination (H_D) of the lift (in cm or inches).
V = vertical distance of the hands from the floor. This must be measured at the origin (V_0) and the destination (V_D) of the lift (in cm or inches).
D = vertical travel distance between the origin and the destination of the lift (in cm or inches).
A = angle of asymmetry – angular displacement of the load from the sagittal plane. This must be measured at the origin and the destination of the lift (in degrees).

RWL must be calculated twice (RWL_{start} and RWL_{end}). Once at the origin of the lift using (H_0, V_0, A_0, and CM_{start}) and once at the destination of the lift using (H_D, V_D, A_D, and CM_{end}). The lowest RWL from these two calculations is to be used to calculate the Lift Index (LI):

LI = (actual load/RWL)

If LI is greater than 1, there may be an increased risk for low-back injury:
- < 1 OK
- = 1 borderline
- > 1 may have increased risk
- > 3 likely have increased risk

(continued)

Table C1. Coupling multiplier (CM).

Couplings	V < 75 cm	V >= 75 cm
Good	1.00	1.00
Fair	0.95	1.00
Poor	0.90	0.90

Good: handles or objects that can be comfortably grasped
Fair: less than optimal handles or load contacted by fingers up to the palm
Poor: bulky, shifting, sagging loads or loads with sharp edges

Table C2. Frequency multiplier (FM).

	Work Duration					
	<= 1 hr		<= 2 hr		<= 8 hr	
Frequency (lifts/min)	V < 75	V >= 75	V < 75	V >= 75	V < 75	V >= 75
0.2	1.00	1.00	0.95	0.95	0.85	0.85
0.5	0.97	0.97	0.92	0.92	0.81	0.81
1	0.94	0.94	0.88	0.88	0.75	0.75
2	0.91	0.91	0.84	0.84	0.65	0.65
3	0.88	0.88	0.79	0.79	0.55	0.55
4	0.84	0.84	0.72	0.72	0.45	0.45
5	0.80	0.80	0.60	0.60	0.35	0.35
6	0.75	0.75	0.50	0.50	0.27	0.27
7	0.70	0.70	0.42	0.42	0.22	0.22
8	0.60	0.60	0.35	0.35	0.18	0.18
9	0.52	0.52	0.30	0.30	0.00	0.15
10	0.45	0.45	0.26	0.26	0.00	0.13
11	0.41	0.41	0.00	0.23	0.00	0.00
12	0.37	0.37	0.00	0.21	0.00	0.00
13	0.00	0.34	0.00	0.00	0.00	0.00
14	0.00	0.31	0.00	0.00	0.00	0.00
15	0.00	0.28	0.00	0.00	0.00	0.00
>15	0.00	0.00	0.00	0.00	0.00	0.00

APPENDIX D1

Questionnaire for the control subjects

Please complete this short questionnaire by circling the number the best corresponds to your opinion.

1. The original task was a realistic task (one that may actually be performed in industry).

1	2	3	4	5
strongly agree	agree	undecided	disagree	strongly disagree

2. I prefer performing the redesigned job rather than the original job.

1	2	3	4	5
strongly agree	agree	undecided	disagree	strongly disagree

3. I experienced more postural discomfort while performing the original job than when performing the redesigned job.

1	2	3	4	5
strongly agree	agree	undecided	disagree	strongly disagree

4. I would have been able to develop a better redesign if I had received some type of instruction on the basic ergonomics of workplace design and manual lifting.

1	2	3	4	5
strongly agree	agree	undecided	disagree	strongly disagree

5. I would have been able to develop a better redesign if I had been given a structured tool to use for the analysis and redesign of the job.

1	2	3	4	5
strongly agree	agree	undecided	disagree	strongly disagree

6. I would have preferred just being told what to do for the redesign rather than redesigning the job myself.

1	2	3	4	5
strongly agree	agree	undecided	disagree	strongly disagree

7. I would have preferred redesigning the job in a group rather than by myself.

1	2	3	4	5
strongly agree	agree	undecided	disagree	strongly disagree

Please answer the following questions. You may use the back of the sheet for additional space if you wish.

1. What would have been different if you were redesigning the job in a group rather than by yourself?

2. Any further comments about any part of the experiment?

APPENDIX D2

Questionnaire for the subjects who receive the ergonomics instruction

Please complete this short questionnaire by circling the number the best corresponds to your opinion.

1. The original task was a realistic task (one that may actually be performed in industry).

1	2	3	4	5
strongly agree	agree	undecided	disagree	strongly disagree

2. I prefer performing the redesigned job rather than the original job.

1	2	3	4	5
strongly agree	agree	undecided	disagree	strongly disagree

3. I experienced more postural discomfort while performing the original job than when performing the redesigned job.

1	2	3	4	5
strongly agree	agree	undecided	disagree	strongly disagree

4. The ergonomics instruction was helpful for redesigning the job.

1	2	3	4	5
strongly agree	agree	undecided	disagree	strongly disagree

5. The ergonomics instruction enabled me to be able to identify more risk factors in the original job than if I had redesigned the job without first receiving the ergonomics instruction.

1	2	3	4	5
strongly agree	agree	undecided	disagree	strongly disagree

6. The ergonomics instruction enabled me to redesign the job with less risk factors than the original job than if I had redesigned the job without first receiving the ergonomics instruction.

1	2	3	4	5
strongly agree	agree	undecided	disagree	strongly disagree

7. I would have been able to produce a redesign of the same quality had I not received the ergonomics instruction.

1	2	3	4	5
strongly agree	agree	undecided	disagree	strongly disagree

8. I would have been able to develop a better redesign if I had been given a structured tool to use for the analysis and redesign of the job.

1	2	3	4	5
strongly agree	agree	undecided	disagree	strongly disagree

9. I would have preferred just being told what to do for the redesign rather than redesigning the job myself.

1	2	3	4	5
strongly agree	agree	undecided	disagree	strongly disagree

10. I would have preferred redesigning the job without having to have gone through the ergonomics instruction.

1	2	3	4	5
strongly agree	agree	undecided	disagree	strongly disagree

11. I would have preferred redesigning the job in a group rather than by myself.

1	2	3	4	5
strongly agree	agree	undecided	disagree	strongly disagree

Please answer the following questions. You may use the back of the sheet for additional space if you wish.

1. What would have been different if you were redesigning the job in a group rather than by yourself?

2. Any further comments about any part of the experiment?

APPENDIX D3

Questionnaire for the subjects who use the NIOSH lifting equation

Please complete this short questionnaire by circling the number the best corresponds to your opinion.

1. The original task was a realistic task (one that may actually be performed in industry).

1	2	3	4	5
strongly agree	agree	undecided	disagree	strongly disagree

2. I prefer performing the redesigned job rather than the original job.

1	2	3	4	5
strongly agree	agree	undecided	disagree	strongly disagree

3. I experienced more postural discomfort while performing the original job than when performing the redesigned job.

1	2	3	4	5
strongly agree	agree	undecided	disagree	strongly disagree

4. I liked using the NIOSH lifting equation to analyze and redesign the job.

1	2	3	4	5
strongly agree	agree	undecided	disagree	strongly disagree

5. The NIOSH lifting equation was helpful to analyze and redesign the job.

1	2	3	4	5
strongly agree	agree	undecided	disagree	strongly disagree

6. Using the NIOSH lifting equation enabled me to be able to identify more risk factors in the original job than if I had redesigned the job without using the NIOSH lifting equation.

1	2	3	4	5
strongly agree	agree	undecided	disagree	strongly disagree

7. Using the NIOSH lifting equation enabled me to redesign the job with less risk factors than the original job than if I had redesigned the job without using the NIOSH lifting equation.

1	2	3	4	5
strongly agree	agree	undecided	disagree	strongly disagree

8. I would have been able to produce a redesign of the same quality had I not used the NIOSH lifting equation

1	2	3	4	5
strongly agree	agree	undecided	disagree	strongly disagree

9. I would have been able to develop a better redesign if I had received some type of instruction on the basic ergonomics of workplace design and manual lifting.

1	2	3	4	5
strongly agree	agree	undecided	disagree	strongly disagree

10. I would have preferred just being told what to do for the redesign rather than redesigning the job myself.

1	2	3	4	5
strongly agree	agree	undecided	disagree	strongly disagree

11. I would have preferred redesigning the job without having to have used the NIOSH lifting equation.

1	2	3	4	5
strongly agree	agree	undecided	disagree	strongly disagree

12. I would have preferred redesigning the job in a group rather than by myself.

1	2	3	4	5
strongly agree	agree	undecided	disagree	strongly disagree

Please answer the following questions. You may use the back of the sheet for additional space if you wish.

1. What would have been different if you were redesigning the job in a group rather than by yourself?

2. Any further comments about any part of the experiment?

APPENDIX D4

Questionnaire for the subjects who receive the ergonomics instruction and use the NIOSH lifting equation

Please complete this short questionnaire by circling the number the best corresponds to your opinion.

1. The original task was a realistic task (one that may actually be performed in industry).

1	2	3	4	5
strongly agree	agree	undecided	disagree	strongly disagree

2. I prefer performing the redesigned job rather than the original job.

1	2	3	4	5
strongly agree	agree	undecided	disagree	strongly disagree

3. I experienced more postural discomfort while performing the original job than when performing the redesigned job.

1	2	3	4	5
strongly agree	agree	undecided	disagree	strongly disagree

4. The ergonomics instruction was helpful for redesigning the job.

1	2	3	4	5
strongly agree	agree	undecided	disagree	strongly disagree

5. I liked using the NIOSH lifting equation to analyze and redesign the job.

1	2	3	4	5
strongly agree	agree	undecided	disagree	strongly disagree

6. The NIOSH lifting equation was helpful to analyze and redesign the job.

1	2	3	4	5
strongly agree	agree	undecided	disagree	strongly disagree

7. Learning and using the NIOSH lifting equation to analyze and redesign the job was more helpful than the ergonomics instruction.

1	2	3	4	5
strongly agree	agree	undecided	disagree	strongly disagree

8. The ergonomics instruction enabled me to be able to identify more risk factors in the original job than if I had redesigned the job without first receiving the ergonomics instruction.

1	2	3	4	5
strongly agree	agree	undecided	disagree	strongly disagree

9. Using the NIOSH lifting equation enabled me to be able to identify more risk factors in the original job than if I had redesigned the job without using the NIOSH lifting equation.

1	2	3	4	5
strongly agree	agree	undecided	disagree	strongly disagree

10. The ergonomics instruction enabled me to redesign the job with less risk factors than the original job than if I had redesigned the job without first receiving the ergonomics instruction.

1	2	3	4	5
strongly agree	agree	undecided	disagree	strongly disagree

11. Using the NIOSH lifting equation enabled me to redesign the job with less risk factors than the original job than if I had redesigned the job without using the NIOSH lifting equation.

1	2	3	4	5
strongly agree	agree	undecided	disagree	strongly disagree

12. I would have been able to produce a redesign of the same quality had I not received the ergonomics instruction and just used the NIOSH lifting equation.

1	2	3	4	5
strongly agree	agree	undecided	disagree	strongly disagree

13. I would have been able to produce a redesign of the same quality had I not used the NIOSH lifting equation and just received the ergonomics instruction.

1	2	3	4	5
strongly agree	agree	undecided	disagree	strongly disagree

14. I would have been able to produce a redesign of the same quality had I not received the ergonomics instruction OR used the NIOSH lifting equation.

1	2	3	4	5
strongly agree	agree	undecided	disagree	strongly disagree

15. I would have preferred just being told what to do for the redesign rather than redesigning the job myself.

1	2	3	4	5
strongly agree	agree	undecided	disagree	strongly disagree

16. I would have preferred redesigning the job without having to have gone through the ergonomics instruction.

1	2	3	4	5
strongly agree	agree	undecided	disagree	strongly disagree

17. I would have preferred redesigning the job without having to have used the NIOSH lifting equation.

1	2	3	4	5
strongly agree	agree	undecided	disagree	strongly disagree

18. I would have preferred redesigning the job in a group rather than by myself.

1	2	3	4	5
strongly agree	agree	undecided	disagree	strongly disagree

Please answer the following questions. You may use the back of the sheet for additional space if you wish.

1. What would have been different if you were redesigning the job in a group rather than by yourself?

2. Any further comments about any part of the experiment?

APPENDIX E

Informed Consent

INFORMED CONSENT FOR PARTICIPANTS OF INVESTIGATIVE PROJECTS

Title of Project: Quantifying the Effects of Participatory Ergonomics

Investigators: Jason J. Saleem, Dr. Brian M. Kleiner

I. THE PURPOSE OF THIS RESEARCH

You are invited to participate in a study concerning participatory ergonomics (PE). Participatory ergonomics is the involvement of workers in the analysis and redesign of their own jobs. This study involves experimentation for the purpose of evaluating the effects of ergonomics instruction and a PE tool in a participatory approach to the redesign of an industrial-type job. This study involves 32 subjects including yourself.

II. PROCEDURES

To accomplish the goals of this study, you will be asked to perform an industrial-type job in the laboratory. After performing the job, you will be asked to redesign the job to make it "safer". You will receive ergonomics instruction and/or receive a tool to assist you in the analysis and redesign of the job (or neither). If you receive the training, you will be given a short slide presentation of basic ergonomics principles. If you receive the tool, you will be shown how to use an online computer program that will assist you in the analysis and redesign of a lifting task. After you finish redesigning the lifting task, you will be asked to complete a questionnaire regarding you participation in the experiment. Participation in this study will be for two consecutive sessions each lasting 1-2 hours. In the first session, you will receive ergonomics instruction and/or be shown how to use the computer program (or neither) and then perform the job that is set up in the laboratory. In the second session, you will analyze and redesign the job and then perform the redesigned job. Through both of these sessions, your heart rate will be continuously recorded with a heart rate monitor which consists of a transmitter that is worn around your chest and a wrist watch receiver. At the end of the second session, you will be asked to complete a short questionnaire concerning the experiment. In order to participate, you must not be or have been an engineering student. Furthermore, you must not have had any prior formal instruction in ergonomics and you must not have had any experience using the NIOSH lifting equation.

III. RISKS

For your safety, the loads that you will be lifting will weigh less than the recommended weight limit given by NIOSH standards for the tasks. The tasks, therefore, are considered "safe" by ergonomics standards and there are no apparent risks to you beyond those encountered in everyday life.

IV. BENEFITS OF THIS PROJECT

Your participation in this experiment will provide information that may be helpful in understanding a participatory approach to redesign. No guarantee of direct benefits has been made to encourage you to participate. If you would like to receive a summary of this research when it is completed, please provide a self-addressed envelope or look for the posting of my thesis in Virginia Tech's Electronic Theses and Dissertations Web site.

V. EXTENT OF ANONYMITY AND CONFIDENTIALITY

The results of this study will be kept strictly confidential. Your written consent is required for the researchers to release any data identified with you as an individual to anyone other than personnel working on the project. The information you provide will have your name removed and only a subject number will identify you during analyses and any written reports of the research.

VI. COMPENSATION

There are two consecutive sessions. You will receive $10 for the first session and $15 for the second. Payment will be made immediately after you have finished your participation.

VII. FREEDOM TO WITHDRAW

You are free to withdraw from this study at any time for any reason with no penalty. You will be compensated for your participation up to the point of withdrawal.

VIII. APPROVAL OF RESEARCH

This research has been approved, as required, by the Institutional Review Board (IRB) for projects involving human subjects at the Virginia Polytechnic Institute and State University and by the Department of Industrial and Systems Engineering.

IX. SUBJECT'S RESPONSIBILITIES AND PERMISSION

I voluntarily agree to participate in this study and I know of no reason why I cannot participate. I have read and understand the informed consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project. If I participate, I may withdraw at any time without penalty.

Should I have any questions about this research or its conduct, I will contact:

(Investigator) Jason J. Saleem – (540) 552-7149

(Faculty Advisor) Dr. Brain M. Kleiner – (540) 231-4926

(Chair, IRB Research Division) H. T. Hurd – (540) 231-5281

_________________________ ____

Print name Subject's signature Date

____

Investigator's signature Date

* Note that the subject and the investigator will each sign two copies of this informed consent. One copy will be given to the subject and the other form will be retained by the investigator.

APPENDIX F

Demographics Sheet

Demographics Sheet

Subject Number:
****

Age: ______

Gender: Male Female (circle one)

Height: ______

Are you a student at Virginia Tech? ______

If "no", where do you attend school or what is your occupation?

Status: (check one)

____ Undergraduate student
____ Masters student
____ Ph.D. student
____ Other __________________________

Department: ____

Major: ____

Have you taken any classes that have dealt with human factors engineering or ergonomics?

If "yes", describe:

Have you ever worked with the NIOSH lifting equation?

Have you ever worked for a shipping company (e.g., UPS, Federal Express)?

If yes, which company and what type of work did you do?

APPENDIX G

Test of Knowledge for Ergonomics Instruction

Please answer the following questions by circling T for True or F for False:

1. Occupational biomechanics is concerned with the interaction of workers with their tools, machines, and materials to enhance workers' performance while minimizing the risk of musculoskeletal injury.	T F
2. While designing a job, you want to maintain the demands of the task greater than the capabilities of the human.	T F
3. At a workstation, or while performing lifting tasks, it is good practice to keep everything within reach.	T F
4. Lifting tasks should be performed between waist and shoulder height.	T F
5. Excessive forces can create a potential for fatigue and injury.	T F
6. It is good practice to distribute contact stress over more surface area of the body.	T F
7. Bent wrists, arms raised high, and twisting of the back are all examples of good working postures.	T F
8. Overloading your physical capabilities does not contribute to injuries.	T F
9. Adjustability makes it easier to customize your workstation to fit your needs.	T F
10. Working in the same posture all day can help prevent fatigue and stress.	T F
11. The quantity and quality of light at a workstation can enhance or obscure the details of your work.	T F
12. You do not need "visual access" (the ability to see what you are doing) for all parts of the task you are doing.	T F
	(continued)

13. A warning sign that has a picture on it generally conveys information more quickly than a sign with just words on it.	T F
14. Unskilled lifting can cause additional mechanical stress on the low back area which can result in back pain.	T F
15. The closer you hold an object to you body, the more torque is applied to your low back.	T F
16. In a squat lift, you use your legs and keep your back straight rather than bending over to pick up the load.	T F
17. Handling aids (e.g., gloves) can reduce physical exertion during manual lifting.	T F
18. Being able to recognizing physical factors that can contribute to injury can help you avoid the unexpected.	T F
19. Glare that shines in your eyes or a low level of lighting can obscure the details of your work.	T F
20. Taking a small number of long breaks is better than taking frequent short breaks to help minimize fatigue.	T F

APPENDIX H

Score Sheet for Risk Factors

Risk Factors Identified: Total: ___________

- ❑ 1. Load is at a far horizontal starting position
- ❑ 2. Load is at a far horizontal ending position
- ❑ 3. Load starts at ground level (low vertical starting position)
- ❑ 4. Load is at a high vertical ending position
- ❑ 5. Large amount of twist
- ❑ 6. Vertical travel distance is long
- ❑ 7. Duration is 8 hours with no breaks
- ❑ 8. Natural curve of the back is not maintained
- ❑ 9. Illumination in the room is low
- ❑ 10. Entire task is done standing – no change of posture (standing *and* sitting)
- ❑ 11. Glare is present on the computer screen
- ❑ 12. Glare in eyes while lifting
- ❑ 13. Height of the computer monitor / angle of tilt
- ❑ 14. Height of the keyboard
- ❑ 15. No handles on the boxes
- ❑ 16. Change in floor level - step

Risk Factors Eliminated: Total: ___________

- ❑ 1. Load is at a far horizontal starting position
- ❑ 2. Load is at a far horizontal ending position
- ❑ 3. Load starts at ground level (low vertical starting position)
- ❑ 4. Load is at a high vertical ending position
- ❑ 5. Large amount of twist
- ❑ 6. Vertical travel distance is long
- ❑ 7. Duration is 8 hours with no breaks
- ❑ 8. Natural curve of the back is not maintained
- ❑ 9. Illumination in the room is low
- ❑ 10. Entire task is done standing – no change of posture (standing *and* sitting)
- ❑ 11. Glare is present on the computer screen
- ❑ 12. Glare in eyes while lifting
- ❑ 13. Height of the computer monitor / angle of tilt
- ❑ 14. Height of the keyboard
- ❑ 15. No handles on the boxes
- ❑ 16. Change in floor level - step

APPENDIX I

Raw Data for Main Dependent Measures

- Type = which condition(s) the subject received
- RF I = risk factors identified in the original job
- RF E = risk factors eliminated in the redesigned job
- LI = lift index
- T original = time to perform the original job (in minutes)
- T process = time to redesign the job (in minutes)
- T redesign = time to perform the redesigned job (in minutes)

Subject	Gender	**Type**	**RF I**	**RF E**	**LI**	T original	T process	T redesign
expert 1	F	both	10	13	1.06	23	64	11
expert 2	F	both	6	9	0.66	23	38	14
subject 01	F	control	5	6	2.34	22	42	12
subject 02	F	both	9	6	1.55	21	38	16
subject 03	F	control	2	6	2.14	29	50	18
subject 04	F	tool	6	3	3.30	25	103	20
subject 05	M	both	8	7	1.98	26	43	18
subject 06	M	both	7	9	1.80	24	31	20
subject 07	F	control	0	8	2.15	24	25	18
subject 08	F	control	3	3	2.66	22	20	18
subject 09	M	both	10	10	2.47	17	23	10
subject 10	M	tool	6	10	0.65	20	44	16
subject 11	F	instruction	6	13	1.93	22	32	12
subject 12	F	tool	1	0	3.72	18	26	12
subject 13	F	both	10	12	1.41	24	34	12
subject 14	F	instruction	9	13	1.43	22	29	18
subject 15	F	instruction	7	8	0.90	18	24	14
subject 16	M	control	3	5	3.06	25	23	23
subject 17	F	tool	3	4	2.53	23	31	12
subject 18	F	both	4	8	1.33	25	74	22
subject 19	F	tool	3	6	0.82	19	33	16
subject 20	M	control	2	9	2.49	18	16	11
subject 21	F	instruction	4	9	1.46	21	23	7
subject 22	M	control	2	6	1.47	19	27	13
subject 23	M	control	4	7	1.90	20	25	15
subject 24	M	tool	8	13	0.88	24	33	20
subject 25	F	both	9	10	1.55	20	23	12
subject 26	M	tool	5	13	0.00	18	39	16
subject 27	M	instruction	4	6	3.20	26	28	12
subject 28	M	instruction	7	13	1.48	20	27	8
subject 29	M	both	5	12	1.13	20	27	16
subject 30	M	tool	4	7	2.19	18	17	12
subject 31	M	instruction	1	1	3.22	21	27	18
subject 32	M	instruction	6	10	1.76	19	16	7

APPENDIX J

Raw Questionnaire Data

- Q1, Q2, Q3… refers to question 1, question 2, question 3…
- The actual questions can be viewed in Appendix D.
- The responses are: 1 = strongly agree; 2 = agree; 3 = undecided; 4 = disagree; 5 = strongly disagree

Control

	Q1	Q2	Q3	Q4	Q5	Q6	Q7
Subject 01	1	1	1	1	1	2	2
Subject 03	1	1	1	2	1	3	4
Subject 07	3	1	1	1	2	4	3
Subject 08	2	1	2	2	2	1	4
Subject 16	2	1	2	2	2	4	1
Subject 20	1	1	3	3	2	4	2
Subject 22	4	2	3	2	3	4	2
Subject 23	1	1	1	3	3	4	2
Total	15	9	14	16	16	26	20
Ave	1.9	1.1	1.8	2.0	2.0	3.3	2.5

Instruction

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9
Subject 11	1	1	1	1	2	1	4	3	5
Subject 14	1	1	1	1	1	1	4	2	4
Subject 15	4	1	1	2	2	3	3	4	5
Subject 21	1	1	2	1	2	2	4	4	4
Subject 27	3	1	1	1	1	2	4	3	5
Subject 28	1	1	1	1	1	1	5	3	4
Subject 31	2	3	2	2	2	2	4	4	4
Subject 32	3	1	2	3	3	2	4	4	4
Total	16	10	11	12	14	14	32	37	35
Ave	2.0	1.3	1.4	1.5	1.8	1.8	4.0	3.4	4.4

(continued)	Q10	Q11
Subject 11	4	2
Subject 14	5	2
Subject 15	3	3
Subject 21	3	4
Subject 27	4	4
Subject 28	5	1
Subject 31	4	3
Subject 32	2	5
Total	30	24
Ave	3.8	3.0

(*continued*)

Tool

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9
Subject 04	1	2	4	1	1	1	2	5	1
Subject 10	2	1	2	1	1	3	2	4	4
Subject 12	2	2	2	2	2	3	3	2	4
Subject 17	1	1	1	2	2	2	3	3	3
Subject 19	1	1	1	1	1	2	2	3	2
Subject 24	2	1	1	1	2	1	2	4	3
Subject 26	2	1	1	3	4	3	3	4	2
Subject 30	1	1	1	3	3	4	4	2	2
Total	12	10	13	14	16	19	21	27	21
Ave	1.5	1.3	1.6	1.8	2.0	2.4	2.6	3.4	2.6

(continued)	Q10	Q11	Q12
Subject 04	5	5	4
Subject 10	4	4	4
Subject 12	4	3	4
Subject 17	3	4	5
Subject 19	4	4	2
Subject 24	4	4	3
Subject 26	4	2	2
Subject 30	4	3	1
Total	32	29	25
Ave	4.0	3.6	3.1

Both

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9
Subject 02	1	1	2	1	1	1	1	1	1
Subject 05	2	1	2	1	2	2	4	1	2
Subject 06	1	1	2	2	2	2	3	2	2
Subject 09	1	1	2	2	3	3	3	2	2
Subject 13	1	2	1	1	1	2	3	2	4
Subject 18	2	2	2	1	1	1	3	1	1
Subject 25	2	1	1	1	3	3	4	1	2
Subject 29	1	1	1	2	2	3	2	2	2
Total	11	10	13	11	15	17	23	12	16
Ave	1.4	1.3	1.6	1.4	1.9	2.1	2.9	1.5	2.0

(continued)	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18
Subject 02	1	1	4	4	4	4	4	4	3
Subject 05	1	2	5	4	5	4	5	4	1
Subject 06	2	2	3	4	3	4	4	4	1
Subject 09	2	4	2	2	4	5	4	4	4
Subject 13	2	2	3	2	4	5	4	4	3
Subject 18	1	1	4	4	5	5	5	5	3

(continued)

Subject 25	1	2	4	3	4	4	4	3	4
Subject 29	2	4	4	2	4	5	4	3	4
Total	12	18	29	25	33	36	34	31	23
Ave	1.5	2.3	3.6	3.1	4.1	4.5	4.3	3.9	2.9

Expert

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9
Expert 01	4	2	2	1	1	1	3	1	1
Expert 02	1	1	1	1	2	2	2	2	4
Total	5	3	3	2	3	3	5	3	5
Ave	2.5	1.5	1.5	1.0	1.5	1.5	2.5	1.5	2.5

(continued)	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18
Expert 01	2	1	2	2	4	5	4	4	3
Expert 02	4	4	3	3	3	5	5	3	4
Total	6	5	5	5	7	10	9	7	7
Ave	3.0	2.5	2.5	2.5	3.5	5.0	4.5	3.5	3.5

APPENDIX K

Raw Heart Rate Data

- Units are beats/min for the first four data columns and % for the last three columns
- Each number represents the *average* heart rate aver the duration of the task
- Resting = resting heart rate; original = heart rate during performance of original job; process = heart rate during the redesign process; redesign = heart rate during performance of the redesign
- % change original = [(original – resting) / resting] x 100%; % change process = [(process – resting) / resting] x 100%; % change redesign = [(redesign – resting) / resting] x 100%

Subject	Type	resting	original	process	redesign	%change original	%change process	%change redesign
subject 01	control	86	105	90	102	22.1	4.7	18.6
subject 03	control	98	129	93	126	31.6	-5.1	28.6
subject 07	control	72	83	71	82	15.3	-1.4	13.9
subject 08	control	83	94	71	85	13.3	-14.5	2.4
subject 16	control	89	102	80	95	14.6	-10.1	6.7
subject 20	control	75	83	69	81	10.7	-8.0	8.0
subject 22	control	84	91	71	78	8.3	-15.5	-7.1
subject 23	control	91	109	86	100	19.8	-5.5	9.9
subject 02	both	80	87	73	83	8.8	-8.8	3.8
subject 05	both	56	77	62	75	37.5	10.7	33.9
subject 06	both	83	90	79	86	8.4	-4.8	3.6
subject 09	both	90	108	96	106	20.0	6.7	17.8
subject 13	both	80	98	79	101	22.5	-1.3	26.3
subject 18	both	78	97	69	91	24.4	-11.5	16.7
subject 25	both	84	113	85	111	34.5	1.2	32.1
subject 29	both	84	107	86	106	27.4	2.4	26.2
subject 04	tool	99	115	89	114	16.2	-10.1	15.2
subject 10	tool	64	85	69	79	32.8	7.8	23.4
subject 12	tool	83	98	80	92	18.1	-3.6	10.8
subject 17	tool	96	105	84	100	9.4	-12.5	4.2
subject 19	tool	91	104	83	96	14.3	-8.8	5.5
subject 24	tool	84	93	80	91	10.7	-4.8	8.3
subject 26	tool	99	106	87	107	7.1	-12.1	8.1
subject 30	tool	84	91	78	87	8.3	-7.1	3.6
subject 11	instruction	91	109	85	110	19.8	-6.6	20.9
subject 14	instruction	67	89	67	97	32.8	0.0	44.8
subject 15	instruction	86	117	96	119	36.0	11.6	38.4
subject 21	instruction	76	92	72	83	21.1	-5.3	9.2
subject 27	instruction	94	103	86	101	9.6	-8.5	7.4
subject 28	instruction	82	105	78	94	28.0	-4.9	14.6
subject 31	instruction	55	67	51	68	21.8	-7.3	23.6
subject 32	instruction	67	78	63	66	16.4	-6.0	-1.5

(Continued)

expert 1	expert	66	82	74	83	24.2	12.1	25.8
expert 2	expert	95	96	87	97	1.1	-8.4	2.1

Standard Deviation of Heart Rate:

Subject	Type	resting	original	process	redesign
subject 01	control	7.38	8.74	9.19	9.20
subject 03	control	7.38	8.83	6.76	8.53
subject 07	control	8.02	9.42	6.86	7.66
subject 08	control	6.40	9.23	6.30	7.75
subject 16	control	6.81	7.16	6.60	8.80
subject 20	control	4.23	4.52	9.91	6.90
subject 22	control	4.30	6.71	5.42	6.20
subject 23	control	5.87	9.30	9.30	9.74
subject 02	both	2.96	8.23	7.24	7.91
subject 05	both	4.32	9.05	6.44	8.47
subject 06	both	3.85	5.20	6.31	4.40
subject 09	both	3.76	5.64	6.84	8.68
subject 13	both	4.47	8.90	12.25	12.23
subject 18	both	5.05	7.58	5.74	7.14
subject 25	both	5.16	8.05	9.17	11.89
subject 29	both	3.49	6.97	4.78	7.84
subject 04	tool	6.02	8.22	10.17	13.49
subject 10	tool	2.17	6.49	8.50	5.86
subject 12	tool	4.81	8.60	8.08	8.77
subject 17	tool	4.41	7.29	9.62	5.75
subject 19	tool	5.44	6.22	6.40	6.13
subject 24	tool	3.98	5.31	7.17	7.70
subject 26	tool	6.41	6.35	7.21	6.17
subject 30	tool	4.64	8.47	9.50	8.89
subject 11	instruction	6.55	6.33	10.70	10.25
subject 14	instruction	5.71	11.34	8.05	10.62
subject 15	instruction	9.21	9.51	10.03	9.30
subject 21	instruction	4.48	8.32	8.34	11.27
subject 27	instruction	4.82	6.20	5.07	7.66
subject 28	instruction	2.28	6.50	4.22	8.66
subject 31	instruction	6.98	8.36	6.74	7.10
subject 32	instruction	4.89	6.65	5.67	6.27
expert 1	expert	8.83	6.87	5.42	8.90
expert 2	expert	4.51	9.00	7.04	5.96

VITA

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Jason is completing his M.S. in the Human Factors Engineering option in the Department of Industrial and Systems Engineering. Jason is affiliated the Macroergonomics and Group Decision Systems Laboratory (MGDSL). Macroergonomics focuses on work system design through consideration of relevant personnel, technological, and environmental variables and their interactions. Before attending Virginia Tech, Jason obtained his B.S. in Industrial Engineering from the University of Pittsburgh. During his stay at the University of Pittsburgh, Jason worked as a co-op student at the Pennsylvania Department of Transportation and Westinghouse Electric Corporation in which he performed industrial engineering projects as well as computer programming. Jason's thesis research is concerned with quantifying the effects of training and a work analysis tool in participatory ergonomics performances. Participatory ergonomics (PE) is a macroergonomics approach in which the end-users actively participate in developing and implementing the technology. PE can be an effective method for involving the workers in analyzing and redesigning their own job. Jason is continuing on for his Ph.D. after completing the M.S. program this year.

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Kirst, M., and Saleem J. (forthcoming). An examination of the cognitive processes involved in mail sorting. Accepted for publication by Ergonomics in Design.