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ERGONOMIC CHALLENGES IN CONVENTIONAL AND ADVANCED APPAREL MANUFACTURING

FINAL REPORT (Phases I through V)

Research Sponsored by:
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Apparel manufacturing is a labor-intensive, assembly line process requiring significant amounts of repetitive, skilled manipulation. A survey of three typical plants in the southeastern United States identified relatively high frequencies of musculoskeletal discomfort among the sewing operators. Poorly designed and maladjusted workstations contributed to these reported problems. Subsequent research found that ergonomic interventions including redesign and proper adjustment of workstations, use of ergonomically-designed seating, and training in low-risk methods and postures substantially reduced these complaints. Other innovations in equipment, job, and organizational design, including adjustable workstations, automation, and modular manufacturing, were also explored. While many of these technologies have potential to improve comfort, safety and efficiency, new ergonomics issues will appear with their introduction. A textbook and videotape to provide manufacturing supervisors instruction in identifying and addressing the most common ergonomic problems in the workplace were developed and are being distributed.

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EXECUTIVE SUMMARY

Apparel manufacturing is a labor-intensive, assembly line process requiring significant amounts of repetitive, skilled manipulation. A survey of three typical plants in the southeastern United States identified relatively high frequencies of musculoskeletal discomfort among the sewing operators. Poorly designed and maladjusted workstations contributed to these reported problems. Subsequent research found that ergonomic interventions including redesign and proper adjustment of workstations, use of ergonomically designed seating, and training in low-risk methods and postures substantially reduced these complaints. Other innovations in equipment, job, and organizational design, including adjustable workstations, automation, and modular manufacturing, were also explored. While many of these technologies have potential to improve comfort, safety and efficiency, new ergonomics issues will appear with their introduction. A textbook and videotape to provide manufacturing supervisors instruction in identifying and addressing the most common ergonomic problems in the workplace were developed and are being distributed.

Enclosed in this document is a summary of the five phases or tasks of this endeavor. The appendices contain the detailed reports of Phases I, II, III, and V. Also, a copy of the training handbook and video (Phase IV) is contained in the appendices.

INTRODUCTION

The United States apparel manufacturing industry is facing difficult challenges. Apparel manufacturing is a labor-intensive, rather than capital-intensive, endeavor. Because it is possible to start up a factory for a few hundred dollars per employee, it is an ideal industry for developing nations. A ready pool of inexpensive labor in the Pacific Rim and Latin American regions provides strong competition for North American manufacturers. In addition, the industry is experiencing a severe shortage of entry-level sewing workers as the population ages and competition increases for young, relatively unskilled personnel. While some of these challenges might be met by innovations in equipment and manufacturing methods, many existing plants are financially unable to invest in new technology.

A high turnover rate (well over 100% each year in many plants) contributes to escalating costs. Months of on-the-job training are needed by novice operators to learn the complex perceptual-motor skills of their trade. On a typical job, novice operators require 12 - 16 weeks of training and practice before their performance reaches established production standards. On especially difficult jobs, as long as 26 weeks may be needed. For most workers, learning curves do not reach asymptote until after one to two years on the job.

Conventional apparel manufacturing is a hand-intensive process as operators rapidly obtain and position parts, guide them through the machine, and dispose of them (Kelly, Ortiz, Folds and Courtney, 1990). As awareness of repetitive motion trauma disorders grows, the industry is experiencing a dramatic increase in reports of upper-extremity injuries and the resulting medical and disability payments. Fines imposed by regulatory agencies for allowing conditions conducive to repetitive motion injuries are expected to add substantially to the already high costs.

A few previous studies have examined ergonomic aspects of the apparel manufacturing industry in the United States and in Europe (e.g., Punnett and Keyserling, 1987; Vihma, Nurminen and Mutanen, 1982). It was desired, however, to broaden the research into an integrated study of ergonomic problems and their potential solutions, covering both conventional and advanced manufacturing, and to disseminate the findings to the industry.

The goals of the research program were to (1) identify and document ergonomic-related problems in the apparel manufacturing workplace, (2) test low cost interventions that would address these problems, (3) identify and explore higher-technology solutions that are beginning to enter the environment, and (4) develop a self-study course in ergonomics specifically designed for apparel manufacturing supervisors.

PHASE I: ERGONOMIC SURVEY IN THE MANUFACTURING WORKPLACE

Method

During the first phase of this program, site visits were conducted at three typical apparel manufacturing plants in the southeastern United States. The primary product line for all three plants was trousers. Plant A employed approximately 500 cutting and sewing operators and was considered to be an innovator in the introduction of new technology; Plant B employed approximately 50 operators and would accept new technology after its was thoroughly proven to be of benefit; Plant C employed approximately 120 operators and was considered financially incapable of adopting significant amounts of new technology. These plants provided a representative cross-section of company sizes and opportunities for automation. (Within months after completion of the survey, Plant B ceased operation after over fifty years in business.)

On a preliminary visit to each plant, management, engineers and floor supervisors were interviewed and the plant was toured in order to develop an overall impression of the ergonomic environment and potential problem areas. During these visits, specific target jobs were identified in each plant for extra scrutiny. These were jobs having indications of ergonomic problems including excessive turnover, absenteeism, physical complaints, or unusually long training periods. These jobs were singled out for later video analyses and detailed workstation measurements. Each of the three plants identified between four and six target jobs. Because of differences in product, procedures, and nomenclature between the plants, there was little agreement on the problem jobs.

During a subsequent series of visits, confidential interviews were conducted with 132 volunteer operators representing the target jobs and other jobs in the plants. These interviews covered (1) demographic factors, (2) musculoskeletal discomfort or injuries, (3) characteristics of the work environment, (4) characteristics of the workstation, chair, and job, and (5) training. Environmental measures of illumination, temperature, and noise were taken at sample workstations throughout the three plants. Detailed anthropometric measurements were taken of the 132 (123 female and 9 male) cutting and sewing operators. Measurements used a GPM Model 101 anthropometer and a GPM Model 106 spreading caliper. All measures were taken with shoes removed. Subjects were measured wearing their own working clothing, typically a lightweight summer type clothing such as shorts, t-shirts or cotton skirts. For standing measures, subjects stood erect, facing forward. For sitting measures, subjects sat erect on a firm, flat surface. Operators were measured on each of ten dimensions considered to be most closely related to the desired workstation dimensions.

Results and Discussion

Anthropometric Data Existing anthropometric databases often are not valid for specific populations of workers (Casey, 1989). This may be especially true where job characteristics self-select for certain physical characteristics in the worker. Smith, Smith and McLaughlin (1982) found that a sample of female textile workers, for example, was substantially taller and heavier than the population norm, probably due to the reaching and lifting requirements of the specific job. It was desired to identify (or rule out) any such gross deviation from population norms among sewing operators. The population of male operators was considered to be too small to provide meaningful data and these measures are not included in the study.

It is apparent from comparing these data that female apparel workers do not deviate in any substantial degree from the dimensions of all female workers as summarized on three other published data bases. The sample of apparel workers may be slightly heavier (as suggested by the larger thigh clearance measurement) but none of the other nine measures varied appreciably from the other published norms. This conclusion, however, may not be valid for every plant. Some plants now employ substantial numbers of sewing operators of Asian/American ancestry and have reported difficulty in adjusting workstations to meet the needs of these typically smaller statured workers. Few of these workers were in the population represented in the current study.

Musculoskeletal discomfort. Another major goal of the program was to document patterns of musculoskeletal injury or discomfort experienced by the sewing operators and to begin relating them to job and workplace elements that might have contributed to them. During the interviews, the sewing operators rated the frequency with which they experienced muscle or joint pain in each of 16 areas of their bodies.

Approximately half of all workers reported that they at least sometimes experience pain in their upper back (52%), neck (49%), and right hand (48%). This prevalence of neck, shoulder, and back discomfort is consistent with results of similar surveys on apparel workers in the northeastern United States (Punnett, Robins, Wegman, and Keyserling, 1985) and in Finland (Vihma, Nurminen, and Mutanen, 1982).

The data are also comparable to those we found in a separate study in which a sample (n=12) of seated sewing operators rated their comfort levels at four different points during the day (Courtney, Kelly, Folds, and Ortiz, 1990). Discomfort tended to increase throughout the day and by late afternoon 10 of the 12 were reporting some degree of discomfort in their upper backs, 6 of the 12 were reporting discomfort in their right hands, and 3 of the 12 were reporting discomfort in their necks.

The working posture. Much of the reported discomfort in the back and neck can be attributed to the working posture of the seated operators. In response to job and workstation characteristics, operators typically adopted a hunched working posture. Analyses of videotape records made of thirty subjects in the target jobs indicated that 40 percent stooped forward (i.e., torso flexion) at least 20 degrees throughout the machine cycle. Sixty percent tilted their heads more than 20 degrees throughout the cycle. Several workers stated that this posture is necessary to obtain maximum production and wages. Such postures have been cited as a factor in muscle fatigue, and discomfort (Grandjean, 1982). The tendency of operators to work in this hunched posture can be attributed to at least three factors, the visual demands of the work, the geometry of the workstation, and inadequate seating.

Illumination. Most sewing operations are visually demanding, requiring the precise stitching of thread into a fabric with which there is little or no visual contrast. Overall, 36 percent of operators stated that illumination was insufficient, requiring them to lean toward the point of operation (POO) in order to see their work. To evaluate this complaint, we measured the average illumination at the POO (consisting of general illumination plus supplementary workstation luminaries) for a sample of 396 workstations. The mean value, 168 foot candles (fc), was less than 60 percent of the Illuminating Engineering Society of North America (IESNA) recommended value of 300 fc for visually intensive tasks with low contrast.

Workstation geometry. The tendency of operators to work in the hunched posture also suggested a potential conflict between workstation geometry and operator dimension. Analyses indicated that the machine treadle typically was located too close (mean=15 cm) to the proximal edge of the work surface. Most commonly, operators responded by positioning the chair away from the work surface in order to allow a knee angle of 110 degrees or greater. From this position, the mean distance from the back of the chair to the point of operation (POO) was only 3 cm less than the arm length of the 50th percentile operator. To compensate for these workstation problems, operators leaned forward to maintain adequate visual and manual access to the POO.

Another factor limiting operator access to the workstation was the location of various obstructions (motors, pneumatic equipment, and machine guards) beneath the work surface. While typical recommended knee room averages about 46 cm, (Eastman Kodak Company, 1983) the presence of these obstructions, in some cases, limited available space to less than 26 cm.

Seating. The vast majority of operations were performed in a seated position. Seating encountered in the sewing environment typically consisted of straight-backed wooden or metal chairs. The provided chairs lacked any cushion for reducing compression and fatigue, lacked adjustable backrests, and often were of improper height. Most operators (91%) customized their chairs with homemade cushions on the pan and backrest in order to adjust the height and increase pliancy. Most cushion adjustments increased seat height by 3-6 cm when compressed.

Repetitive Manipulation. One primary risk factor for the development of repeated trauma disorders is the frequency with which motions are repeated. On the basis of observation and interviews with an experienced methods engineer, the sewing jobs were classified as requiring high, medium, or low amounts of repetitive manual manipulation. While the classification was somewhat subjective, it was closely related to the frequency of changes in hand and wrist posture. High degrees of manual manipulation were associated with higher levels of physical discomfort almost throughout the body. Greatest discomfort levels were concentrated in the neck, upper and middle back, right shoulder, and hands. Seventy-three percent of the high manipulation workers reported pain in their right hands, the highest discomfort frequency identified in the analyses. This is consistent with the findings of Vihma, et al. (1982) of a significant relationship between hand pain and repetition rates.

In addition, as many as 100% of operators on certain high manipulation jobs (e.g., top-stitching) reported symptoms that are often associated with repetitive trauma disorders, including nocturnal numbness in the hands and fingers. In the overall population of sewing operators interviewed, the incidence of such reported symptoms was approximately 30%, a somewhat higher incidence than has been previously reported (e.g., Punnett and Keyserling, 1987). Our higher frequency can partially be attributed to the interview sample that was purposely weighted to emphasize problem jobs.

The cycle time of the 14 target jobs ranged from 10 to 109 seconds with most in the 20 to 40 second range, very similar to the cycle times recorded by Punnett, et al. (1987). There were an average of 29 left hand and 25 right hand posture changes per cycle. The most frequent hand and wrist postures included pinch (lateral and pulp), ulnar deviation, flat press, extension, and flexion, respectively.

Training. Initial training of sewing operators was performed on the job in all three of the plants examined. One plant had a specialized training department responsible for initial and continuing training; the other two plants provided training by the floor supervisors. Training periods varied from a few days to as many as six months. None of the plants provided specialized instruction in effective training techniques for their supervisors or training staff.

There was evidence that improvements in operator training are being made, especially for newly hired workers. Higher percentages of younger operators reported receiving job-methods training using visual aids or videotape, training on posture, training on lifting, and training on other safety issues. As suggested by the table, videotape is only infrequently used during initial training but is more commonly used for cross-training the more experienced operators. Training feedback was, at best, inconsistent. After the initial hour or so of intensive training, return visits by the trainer/supervisor were sporadic. One plant posted a daily learning curve chart on the novices' workstations but even this degree of performance feedback was unusual.

PHASE II: LOW COST ERGONOMIC INTERVENTIONS

Relatively low cost solutions are available that can address much of the musculoskeletal discomfort reported by the operators in the initial survey. Badly designed and adjusted workstations can be properly adjusted for the operators; ergonomically-designed seating can replace the hard, unadjustable seats.

While most sewing operators continue to sit on hard, unadjustable seats during the workday, ergonomically designed chairs for the sewing operator are now available (Yu and Keyserling, 1989). These chairs have easily adjustable seat height, seat pans, and backrests. They are adequately padded and promote a lordotic seated posture. Little formal effort had been made to validate the effectiveness of these chairs in the manufacturing environment. The goal of this study was to provide a field evaluation of the effects of workstation adjustments, posture training, and ergonomically designed seating on the comfort, posture, and production efficiency of sewing operators.

Method

Two studies were conducted on the effects of ergonomically designed chairs on posture, comfort, and production efficiency in cut-and-sew manufacturing plants. In the first study, ergonomically designed chairs were tested on the sewing floor of a trouser manufacturing plant (Courtney, et al., 1990). Twelve sewing operators took part in the study. Before initiation of testing, all operators rated their levels of musculoskeletal discomfort in fifteen areas of their bodies at approximately two-hour intervals during the work day to provide baseline comfort/discomfort levels. The subjects were videotaped from the side as they worked so that measures of postural angles could be made.

The operators were divided into two groups of six each. The six operators in the control group then received instruction in proper working posture and were individually given recommendations on adjusting their workstations and chairs to ergonomically appropriate configurations. The six subjects in the experimental group received the same posture training and workstation recommendations; in addition, they were supplied with the ergonomically designed chairs and carefully trained in their use.

After a period of approximately five weeks, the sequence of discomfort surveys and videotaping was repeated.

A subsequent study tested ten sewing operators in two different plants (Peck, 1990). One plant produced active-wear such as sweatshirts; the second produced medical supplies. This study used the same discomfort survey and videotape posture analysis but employed a before-and-after experimental design rather than matched groups.

Results and Discussion

The changes were remarkable. In the first study, the experimental group showed substantial improvements in both posture and frequency of musculoskeletal discomfort. The mean improvement in back angle was 8.3 degrees with five of the six subjects showing improvement. Reported musculoskeletal pain decreased by 90.3 percent. The control group showed a mean 2.5 degree improvement in back posture with three of the six subjects showing improvement. Reported musculoskeletal discomfort decreased by 53.6 percent. No change in production was seen, however, for either group.

In the subsequent seating study, the changes in posture were not as pronounced as those found during the first study. The subjects, however, reported an almost identical 90% reduction in discomfort frequency when using the ergonomically designed chairs. A statistically significant increase in production was experienced by subjects in one of the two plants after introduction of the ergonomic chairs. Given the choice, 15 of the 16 operators who tested the ergonomic chairs during the two studies elected to keep them after the conclusion of the studies.

In field studies of this kind, the experimenter must be mindful of potential contamination of the data by the Hawthorne effect, by the demand characteristics of the study, or by other aspects of the situation that are not under strict control. Traditionally, the Hawthorne effect is most evident in increased production on operator-paced jobs. To explore the possibility of such an effect, we compared production data during the five weeks of the study with historical and post-study data from the same operators. Only one of the three test sites experienced any change in production efficiency that could not be directly attributed to identified outside factors. We attribute the lack of evidence for a Hawthorne effect to at least two factors. First, great care was taken to make the experimental procedures as invisible as possible to the operators. Second, the plants in which the studies took place were relatively innovative and small experiments like this were a typical part of the operators' jobs.

PHASE III: EXPLORE HIGHER TECHNOLOGY MANUFACTURING TECHNOLOGIES

Some plants, especially the larger ones, are beginning to recognize and address ergonomic and workstation problems through the introduction of relatively advanced manufacturing technologies. These include such approaches as job automation, automated materials handling, ergonomically improved workstations, and the introduction of modular manufacturing cells. Many of these approaches bring with them new or revisited problems and challenges for the ergonomist. During this phase of the program, we explored and documented emerging technologies in the apparel manufacturing industry through experimentation, interviews with equipment manufacturers, apparel manufacturers, and manufacturing personnel.

Automated Materials Handling

In conventional manufacturing operations, boxes of parts and bundles of approximately 40 unfinished garments are carried, dragged, or wheeled on specially designed carts between workstations. Materials movement is done by the operators, themselves, or by designated "bundle boys." Automation of this materials handling process has received a significant amount of attention, perhaps to the detriment of other automation opportunities (Weissbach, 1986). Various vendors are now introducing automated equipment that is designed to make this materials handling more efficient.

A unit production system (UPS), a computer-controlled overhead conveyor, may be used to move hangers of parts or partially assembled garments from one workstation to the next. Rather than large bundles of parts, each hanger typically carries the components of a single garment or a small number of garments.

In one plant that was surveyed, 100 workstations were connected by a typical automated, ceiling-mounted UPS line that carried individual unfinished garments on hangers. A central computer tracked each garment as the bar coded hanger passed by a series of bar code readers on the conveyor line. The garment was automatically moved to the next operation and routed to one of the sewing operators according to the UPS's preprogrammed logic. The garment typically was delivered to the appropriate workstation in a queue near the operator's left shoulder.

Some operators complained about a perceived increase in the noise level and reported temporary auditory threshold shifts during and after the workday. The noise level peaks at the operators' ears, largely produced by impacts between the heavy plastic hangers as they dropped into the queue for the workstation, was measured at between 95 dB and 97 dB at a majority of the workstations. These peaks, occurring every few seconds (depending on the length of the operation cycle at the workstation), were superimposed over a continuous noise level of 82 - 88 dB.

The UPS reduced horizontal reach requirements and all but eliminated heavy lifting by the operators. It resulted, however, in increased vertical reach requirements and increased wrist pronation during acquisition of materials. Interviews on body part discomfort with a sample (n=12) of operators on the conveyor line indicated slightly higher frequencies of hand and leg discomfort among this sample than among their counterparts who utilized conventional materials handling.

Operators on the UPS line expressed dissatisfaction with the "intelligence" of the automated controller. Although the system was designed to be operator paced, faster operators reported that they often experienced empty queues at the same time that work was still being routed to the slower workers. Other difficulties included "ghost hangers" that had dropped their bundles somewhere but were still being moved through the system and counted as units of production.

Perhaps the greatest problem with the UPS was its lack of flexibility and the difficulty in making short-term changes in its logic. Slight changes in the production process, for example reassigning a given workstation to do a different operation for a single day, or temporarily changing the work flow for a short run of a different product could not be done economically. This UPS installation was eventually idled and abandoned when the company changed their product line to a different garment and determined that the UPS could not cost-effectively be altered to support the new product.

Workstation Automation

Many leaders in the industry believe that a solution for some of the training and ergonomic problems lies in partial automation of selected manual manufacturing operations. Automation, for example, can reduce the skill requirements of a complex positioning and guiding task so that novice operators might reach acceptable levels of production within a period of days or weeks rather than the several months currently required. Partial automation can also eliminate many high-risk hand and wrist postures and the frequency of hand movements, thereby reducing the exposure to common repetitive trauma disorders.

There are significant technological barriers to the introduction of complete automation to the sewing workstation. Much of the difficulty is due to the nature of the raw material, fabric. Unlike relatively rigid materials such as metal, plastic, or ceramics, a single ply of fabric is difficult to push or pull or to hold in position with the degree of accuracy required in the manufacturing process. Workstation automation, therefore, must (1) concentrate on operations in which precision is not required, (2) find techniques for making the fabric "act" rigid, and (3) use a hybrid approach in which human operators continue to feed and guide the machines during precise tasks.

Automated cutting machines now being introduced into the industry are programmed to cut stacks of fabric parts precisely and in a given order from a "spread" of 100 or more plies of fabric. By creating a partial vacuum under the porous tabletop, air pressure is used to hold the thick stack of fabric rigidly in place. Cutting of the spread is done automatically by a cutting blade, cutting at speeds up to 2000 cm/minute, under control of the computer.

Partial automation of sewing operations can eliminate some of the risk factors for CTDs. As an example, production of a "felled seam," the kind of double overlapped seam found on the side of denim jeans, requires an awkward posture of wrists, hands, and fingers to hold the fabric in position as it is guided through the sewing machine. This job generally requires over six months of training time and it has a disproportionate incidence of hand and wrist injuries. In recent years, a folding attachment for the sewing machine has become available that guides the fabric edges into the appropriate double-overlapped position eliminating many of the operators' motions and awkward hand postures. A more recent innovation, an automated felled seamer, simplifies the job even further, allowing the operator to use nearly neutral wrist and hand postures throughout the operation. In addition to reducing the incidence of repetitive trauma injuries, this is expected to reduce training time by a substantial amount (Textile Clothing Technology Corporation, 1989).

Workstation Adjustability

Numerous ergonomists have recommended the use of tilted tabletops to reduce wrist and back angles and to improve visibility during sewing operations. A rapidly adjustable workstation was selected for use in testing this hypothesis. The height of the top was adjustable between 71 cm and 110 cm (28 in and 43 in). The top surface of the workstation could be tilted through angles of +15 degrees through -15 degrees. All adjustments could be made by the operator using a pair of handles below the work surface controlling two hydraulic cylinders. In the Southern Tech AMTC, a Pfaff 463 machine was mounted on the workstation and the operator worked from a seated position.

Tests of the effectiveness of different tilt angles of the work surface were conducted. The sewing operator assigned to that workstation performed the task at worktable angles of 0 degrees, +15 degrees, and -15 degrees. Videotapes of back and wrist posture were taken as the operator worked and the operator was interviewed at the end of the series of trials. Results indicated no significant difference in wrist or seated postures that could be ascribed to the tabletop angle. The operator, however, expressed a strong preference for positions in which the back of the workstation is tilted upward.

Operator Real-Time Information System

Operators who receive near-real-time information feedback about the level of their performance might be expected, according to behavioral principles, to improve their performance. Real-time production management systems are reaching the work floor to track the location and flow of particular bundles, and the status and performance of individual workstations. Terminals at each individual workstation are connected to a central computer system. Managers and supervisors have access to this information to aid in production management and planning. Similar data may be available on the terminals at each workstation but it is not easily obtained and interpreted.

GTRI designed and prototyped a real-time display system that would allow the operator to establish production goals and would provide the operator with continuous information, in bar-graph form, of progress toward meeting the established goals. A touch-screen system on the small color monitor could be used to sign on and off, establish goals, change goals, determine total earnings and projected earnings for the day, and perform other display-control functions. The real-time display system could be integrated with the information network on a real-time production management system, like those currently in existence, to provide these data at selected workstations. The system would be most cost-effective if used in conjunction with operator training and retraining.

PHASE IV: TRAINING VIDEO AND MANUAL

Based on the results of the research in the first three phases, a 100 page manual and 30 minute video entitled "A Stitch In Time: The Supervisor's Guide to Ergonomics" were developed as a training package for apparel manufacturing supervisors. Written at approximately the eighth grade comprehension level both manual and video contain 5 corresponding sections. The first is entitled "Making the job fit the worker" and provides a working definition of ergonomics. Section two, entitled " Work station design", focuses on the relationship between posture and the design of the work station. Section three, "What are CTDs", is concerned with defining the major cumulative trauma disorders and discussing the risk factors and possible solutions. Section four, "The work environment", concentrates on the influence of noise and lighting on worker performance and section five, "Training and retraining workers", is primarily concerned with training concepts important to the supervisor.

User testing of the manual at an apparel plant in Georgia suggested that, overall, the manual was written at the right level. The key feature most often noted by participating supervisors was the strategic use of pictures to illustrate the concepts. Over 770 companies and institutions have purchased more than 2100 copies of the training package (Appendix A contains the latest list of companies). The success of the manual and video has been largely due to the tremendous publicity both received in a wide variety of publications and journals (Appendix B contains the list of publications).

PHASE V: MODULAR MANUFACTURING SYSTEMS

There are currently significant efforts under way to eliminate the progressive bundle assembly-line process and to introduce the concepts of modular manufacturing cells into the apparel manufacturing workplace. In this concept, a complete garment (or major sub-assembly) is produced in a modular cell of, perhaps, ten operators and twenty machines. Operators are not assigned to a single operation but may move between workstations as the flow of product requires. Individual workstations are typically shared by two or more operators. In contrast to traditional management practices, the team of operators in the cell is responsible for many elements of workflow planning and management, team formation and interpersonal relations, and product quality. Because modular cells are rapidly reconfigurable, modular manufacturing has been promoted as an efficient way of providing a quick response to the common need for a short production run of a particular product.

Attempts to introduce modular manufacturing have produced inconsistent results with both notable successes and distressing failures. Anecdotal reports suggest that, after a period of adjustment, many workers experience significantly decreased levels of musculoskeletal discomfort due to the increased variety in movements, to improved postures at the standing workstations, and to motivational factors. Increased morale and workgroup cohesiveness, along with substantially reduced absenteeism, have also been seen in successful implementations.

Numerous ergonomic questions and challenges appear during the implementation of the modular system. Many traditional workstations will need to be redesigned. Increased adjustability/adaptability will be required for workstations that are shared by two or more operators. Issues of job design, training, organizational design, performance assessment and reimbursement will need to be successfully addressed.

As one example of ergonomic issues in workstation design, some implementations of modular cells have required a switch from a primarily sitting workplace to a primarily standing workplace because of the need for operators to move between the workstations in the module. This necessitates redesign of machine controls since the traditional sewing machine foot treadles are not usable from a standing position and existing standing foot controllers do not provide the necessary level of sensitivity for precise machine control. Several designs of new foot-actuated controllers have recently been introduced but none has proven entirely satisfactory.

In unsuccessful attempts at implementation of modular manufacturing, reduced individual production is often attributed to the lack of specialization by operators and to less efficient material handling techniques. Inability to effectively plan and manage production within the cell, interpersonal problems, and dissatisfaction with new group-incentive pay schemes are also cited as problems. Other ergonomic problems related to job, workstation, and workgroup organization are certain to become apparent as the apparel industry's experience with modular manufacturing systems expands.

Our data indicate that the overall degree of discomfort reported by standing modular operators does not differ significantly from that reported by seated operators in progressive-bundle plants. Standing modular operators report somewhat more foot pain (possibly related to inadequate control devices) and somewhat less pain in other parts of the body (related to posture changes). Operators reported that subjectively they noticed a decrease in musculoskeletal discomfort on moving from bundle to modular processing. For this and other reasons, operators' preference favored modular systems by a wide margin. There is nothing in the discomfort reports that would argue against standup modular work. Substantially more work, however, needs to be done on the development of machine controllers for standup operators.

CONCLUSIONS AND PROSPECTS

The apparel manufacturing industry in the United States presents significant challenges for the ergonomist. A large percentage of plants are experiencing marginal profitability and can afford no more than quick, band-aid solutions to their ergonomic problems. For these organizations, the ergonomist has much to offer in terms of recommendations for workstation geometry adjustments, improved seating, and improvements in workstation lighting and noise protection. Highly motivated plants are able to develop inexpensive and ingenious solutions to many of the problems that are brought to their attention.

Other, more prosperous organizations are able to experiment with introducing some one or more of the elements of new technology described above. Ergonomically designed seating should be a top priority, but companies often need assistance to distinguish between well designed chairs and those that are "ergonomic" in name only. Other elements of workstation and materials handling automation are becoming popular but managers can certainly use the services of an ergonomist to help lead them through the kinds of pitfalls described above.

Many plants still operate under an unenlightened management philosophy that rejects the application of ergonomics practice. Managers fear that it will "plant seeds of suspicion" in the workforce and lead to increased malingering and frivolous workers' compensation claims. The authors have frequently heard the opinion expressed that cumulative trauma disorders are a contagious psychosomatic affliction spread primarily through contact with union organizers and personal injury attorneys. It is worth noting that even in these plants the sewing operators have a vague recognition of their ergonomic problems. They need not be told, for example, that their chairs are uncomfortable and that their backs ache. They are aware of occupational injuries through media reports and discussions with their coworkers.

An increasing number of apparel manufacturing plants, however, are adopting a more enlightened attitude toward ergonomics. A few large companies have added full-time ergonomists to their management teams; a larger number of companies are using outside consultants to help organize and support inplant ergonomic projects.

One of the most important roles the ergonomist can play is educating the plant management, floor supervisors, and workforce. Managers need to be aware of the importance (for both humanitarian and cost reasons) of a continuous program of surveillance with a goal of detecting ergonomic problems before they are translated into acute or cumulative injuries. Plant floor supervisors need to be educated to support this surveillance program by recognizing symptoms of ergonomic problems including maladjusted workstations, inadequate seating, inadequate illumination, and high-risk working postures and motions, by helping to identify intervention strategies and by training workers to do the same. Ortiz, Kelly, and Davis (1991) have prepared a workbook and accompanying videotape specifically designed to educate the apparel plant floor supervisor in ways to fulfill this role.

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APPENDICES

APPENDIX A

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Valley Park, MO 63088
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ACCO Swingline
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708-541-9500

Ace Hardware Corporation
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Adams, John
EDL

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Canon
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CNA Insurance
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8403 Colesville Rd.
Silver Spring, MD 20910

CNA Insurance Companies
Attn: Bill Morris
Eastern Regional Office
9 Entin Road
Parsippany, NJ 07054

Coats & Clark Inc.
Attn.: Mike Bell
901 Clark Avenue
Albany, GA 31705

Collins & Aikman
Attn.: Anna M. Wyke
Property/Casualty Analyst
Science & Service Division
P.O. Box 32665
Charlotte, NC 28232
704-547-8500

Combustion Technologies Inc.
Attn: Richard J. Breese
4515 Cantrell Road
Flowery Branch, GA 30542
404-967-2300

Community Memorial Hospital
Attn: Harriet Evans
1002 Comstock Drive
Deer River, MN 56636
218-246-2902

Cone Mills Corporation
Attn.: Ken Blake
1201 Maple Street
Greensboro, NC 27405

Console Systems Inc.
Attn.: Theresa Montoya
6357 Arizona Circle
Los Angeles, CA 90045

Consolidated Diesel Company
P.O. Box 670, U.S. Highway 301
Whitakers, NC 27891
919-437-6611

Constangy, Brooks, & Smith
Attn: William K. Principe
Suite 2400
230 Peachtree Street, N.W.
Atlanta, GA 30303-1557
404-525-8622

Continental Insurance Company, The
Attn.: David Mahone
Department 2B
1 Continental Drive
Cranbury, NJ 08570-2103

Cooper Industrial Products
Attn.: Carol Musser
Divisional Quality Assurance
725 West Eleventh Street
Auburn, IN 46706
219-925-0700

Cooper Industries
Wagner Lighting
Attn.: Linda A. Feig
Employee Relations Assistant
2nd & Jefferson Street
Boyertown, PA 19512
215-367-2604

Coopertools
Crescent / Xcelite Plant
Sumter, SC

Corbin, Ltd.
151 West Lynn Avenue
Ashland, KY 41102

Courtright, John F.
1029 Jefferson St., N.E.
Albuquerque, NM 87110

Coutts Library Services Inc.
736 Cayuga Street
Lewiston, NY 14092

Creaciones Pop, S.A. de C.V.
Attn: Jamie Darwich Agami
Calle 28 No. 90-A
Col. Federal
15700 Mexico D. F.

Creation Windows, Inc.
Attn: M. Anderson
131 Ben Burton Circle
Bogart, GA 30622

Critikon
Attn: Herbert E. Brown
West Queen Street
Southington, CT 06489
203-621-9111

Crown Crafts, Inc.
Attn: Ray Alexander
Edmond Street
Calhoun, GA 30701
404-629-7941

Current Inc.
Attn.: Nurses Station
1025 E. Woodman Road
Colorado Springs, CO 80920

DCS & Associates, Inc.
Attn.: Dale C. Spencer
President
121 E. Rosewood Avenue
Alamo Office, Suite 100
Boerne, TX 78006

Dal-Tile Corporation
Attn.: Doug Orner
211 N. Fourth Street
Gettysburg, PA 17325
717-334-1181

Dallco Industries Inc.
Attn.: Nancy L. Traxler
Director of Safety and Health
P.O. Box 2727
York, PA 17405-2727
717-854-7875

Dalton College
Jane Secord, Bookstore Manager
213 North College Drive
Dalton, GA 30720
404-272-4418

Dan River Inc.
Attn.: C. W. Ezell
P.O. Box 261
Danville, VA 24543

Dan River Inc.
Attn.: C. W. Ezell
Director of Safety
P.O. Box 261
Danville, VA 24543

Dayton Bag & Burlap Company
Attn.: Carrie E. Magoto
322 Davis Avenue
Dayton, OH 45403
513-258-8000

DBH Ltd., Inc.
Attn.: Bob Hicks
P.O. Box 315
158 Sunrise Drive
Adamsville, TN 38310
800-852-3026

Defense Logistics Agency
Attn.: Ann Lawrence
Production Division
Cameron Station
Alexandria, VA 22304-6100

Delco Electronics
Attn.: K. C. Crombie, E104
6767 Hollister Avenue
Goleta, CA 93117

DeLong, Inc.
Attn.: Allen Hillgartner
733 Broad Street
Grinnell, IA 50112

Dentsply/York Division
Attn.: S. E. Emig
P.O. Box 872
York, PA 17405-0872
717-845-7511

Desa International
Attn.: Dave Keown
P.O. Box 90004
Bowling Green, KY 42102

Design Organization, Inc.
103 E. Indiana Avenue
Valparaison, IN 46383

Detroit Receiving Hospital
Attn.: James Russell, R.N.
4201 St. Antoine
Detroit, MI 48201

Diesel ReCon Company
Attn.: Nina Harris
2680 Pershing Avenue
Memphis, TN 38112
901-320-3200

Disneyland
Attn.: C. Piszczek, Safety
1020 W. Ball Rd., Bldg. 200
Anaheim, CA 92802
714-999-4000

Ditzel Communications
Attn.: David L. Ditzel
President
7929 Liberty Road
Baltimore, MD 21207
301-655-8858

Dixon, Archie D.
3720 Wolf Pond Road
Monroe, NC 28110

Dominion Yarn Corporation
Attn.: Michael W. Stokes
Corporate I.E. Manager
P.O. Box 8105
Landis, NC 28088-8105
704-857-1121

Don Brown Productions
Attn.: Don Brown
867 N. Main Street
Orange, CA 92668

Don'l Inc.
PO Box 666
Highway 441 North
Clayton, GA 30525
404-782-4241

Dorsey, Charles

Duck Head Apparel Company
220 East Athens Street
Winder, GA 30680

Duke University
Attn.: Dr. Samuel D. Moon
Bay B 102
Erwin Square
Occupational Medicine
Durham, NC 27710

Dundee Mills, Inc.
Attn.: Mike Petruna
Corporate Safety Director
P.O. Drawer E
Griffin, GA 30224
404-227-5581

Dundee Mills Inc.

Dyersburg Fabrics Inc.
Attn.: Mark Jamison
P.O. Box 767
East Phillips Street
Dyersburg, TN 38025-0767
901-285-2323

Dynabrade, Inc.
DBWO1
8989 Sheridan Drive
Clarence, NY 14031
716-631-0100

E. F. Johnson Company
Attn.: Annette K. Lord, R.N.
Occupational Health Nurse
P.O. Box 1249
Waseca, MN 56093-0514
507-835-6222

E. R. Moore Company
Attn.: Zoe Larkin
1810 West Grace Street
Chicago, IL 60613

E. I. Du Pont De Nemours & Co., Inc.
Sabine River Works
P.O. Box 1089
Orange, TX 77631-1089

E-Z-Go, Textron
Attn.: Penny C. Smith
P.O. Box 388
Augusta, GA 30913

Eastwood Environmental Inc.
Misko Maynard
4326 N.E. Killingsworth
Portland, OR 97218-2446

EBI Companies
Attn.: Carl R. Rockstroh, CSP
Four Greenwood Square
3325 Street Road, Suite 220
Bensalem, PA 19020
215-245-0600

EBI Companies
Attn.: Lora Wernsman
Loss Control Clerk
P.O. Box 90349
Indianapolis, IN 46290-0349
317-575-0989

Edwards, Barbara R.N.
1600 Mockingbird Lane
Southlake, TX 76092

Efficient Engineering Co., Inc.
Attn.: Russel Kennedy
130 Town Center Drive
Troy, MI 48084-1723

EG&G Rotron
Custom Products Division
Woodstock, NY 12498
914-679-2401

ElectriCities of North Carolina, Inc.
Attn.: Library
P.O. Box 29513
Raleigh, NC 27626-0513

Electronics & Space Corporation
Attn.: Evelyn Horkman
8100 W. Florissant
Sta. 2492
St. Louis, MO 63136
314-553-3691

Elf Atochem North America, Inc.
17168 W. Jefferson Avenue
Riverview, MI 48192-4270

Employers Casualty Company
Attn.: Dean Duncan
Director, Technical Resource Center
P.O. Box 2759
Dallas, TX 75221

Engelhard Corporation
Attn.: Charles H. Hatfield
Area Safety Manager
Specialty Chemicals Division
McIntyre, GA 31054
912-946-7536

Ennis Lumsden Boylston & Associates, Inc.
Attn.: Edith Eubanks
Office Manager
605 Eastowne Drive
Chapel Hill, NC 27514
919-967-2228

Environmental & Safety Services, Inc.
Attn.: David Schemenauer
P.O. Box 7305, Department 141
Kansas City, MO 64116
816-459-4100

Environmental Technology Connection, Inc.
Attn.: Harold Trenouth
VP Operations
118 Great Road, Suite 220
Stow, MA 01775
508-897-4462

Epstein Becker Mulkeen & Green
Attn.: Robert A. Dye
1875 Century Park East
Los Angeles, CA 90067-2501
213-556-8861

Ergo International
Attn.: Ben
361 N. Bernoulli Circle
Oxnard, CA 93030
818-504-0020

ESCOD Industries
Attn.: David Byers
Royal Gorge Industrial Park
Canon City, CO 81212
719-275-7595

Esselte Meto
Attn.: D. Howard Randall
6750 Belt Circle Drive
Bedford Park, IL 60638
708-594-4433

Evanston Hospital
c/o Receiving Department
2700 Girard Avenue
Evanston, IL 60201

Excel Corporation

Express Cororate Workspace
4303 Pleasantdale Road
Doraville, GA 30340
404-263-0789

Fairfield Chair Company Office
Attn.: Dody Lackey
1331 Harper Avenue, S.W.
Lenoir, NC 28645
704-758-5571

Farber Bag & Supply Company
Attn.: Jim Farber
8733 Kapp Drive
Peosta, IA 52068

Farm Fresh Catfish Company
P.O. Box 85
Hollandale, MS 38748
601-827-2204

Fashion Institute of Technology
Attn.: Library
227 West 27th Street
New York, NY 10001

Fayetteville Manufacturing Corporation
P.O. Box 1359
Fayetteville, NC 28302

Felton Brush Inc.
Attn.: Sandy Brucher
315 Wilson Street
Manchester, NH 03105-0538
603-669-1970

Fender Musical Instruments Corp.
Attn.: Al Guzman
1163-A Pomona Road
Corona, CA 91720
714-734-8530

Fenton Art Glass Company
Attn.: Mike Fenton
700 Elizabeth Street
Williamstown, WV 26187

Fieldcrest Cannon, Inc.
Attn.: A. Lee Ivester
One Lake Drive
Kannapolis, NC 28081

Fieldcrest Cannon, Inc.
Attn.: Louis Dew
Blanket Finishing Mail
Warehouse Street
Eden, NC 27288

Fieldcrest Cannon, Inc.
Attn.: Peggy G. Martin, R.N., C.O.H.N.
Director, Employee Health Programs
326 E. Stadium
Eden, NC 27288

Findlay Industries, Inc.
Attn.: Martin Terry
4000 Fostoria Road
Findlay, OH 45840
419-422-1302

Fireman's Fund Insurance Company
Attn.: Ron Manford
Regional Loss Control
P.O. Box 888699
Atlanta, GA 30356
404-399-7019

Fireman's Fund Insurance Company
Attn.: Mr. Wayne Weirich
Loss Control Supervisor
4435 Waterfront Dr., Suite 100
Glen Allen, VA 23060

Firestone Fibers and Textiles Company
Attn.: Bill Passmore
1101 W. Second Avenue
P.O. #JB 15451
Gastonia, NC 28053-1278

First National Bank of Griffin
Attn.: Carol M. Jones
Personnel Officer
P.O. Drawer F
Griffin, GA 30224
404-227-2251

Flexsteel Metal Division
Attn.: Gary Koehler
3400 Jackson Street
Dubuque, IA 52001

Flow Design
8908 Governors Row
Dallas, TX 75247-3798
214-631-0011

Foreign Broadcast Information Service
Suite 163
201 Elden Street
Herndon, VA 22070
703-733-6547

Forster Manufacturing Co., Inc.
Attn.: Nancy Morgan
Safety & Workers' Compensation Supervisor
P.O. Box 657
Wilton, ME 04294-0657
207-645-2574

Fort Howard Corporation
1919 S. Broadway
Green Bay, WI 54304
91-9767
414-435-8821

Fred Jones Manufacturing Company
Main Street and Fred Jones Avenue
Oklahoma City, OK 73125

Freitex, Inc.
1300 W. Oakridge Drive
Albany, GA 31708
912-436-7266

Friedman Bag Company, Inc.
Attn.: Alvin Lanfeld, President
P.O. Box 866004, Terminal Annex
Los Angeles, CA 90086-6004
213-628-2341

Fruit of the Loom Canada, Inc.
Attn.: Robert Lamothe R-08193
3200, Chamberland
Trois-Rivieres (Quebec)
819-379-7631

Gamet, John
150 Crescent Knoll Dr.
Libertyville, IL 60048

Garan
350 Fifth Avenue
New York, NY 10118-10164
212-563-2000

Garvey Corporation
William J. Garvey, Vice President
Route 73
Blue Anchor, NJ 08037

Gas Company, The
Lyn Berman
555 W. Fifth Street
Los Angeles, CA 90013-1011
213-244-3245

Gasboy
Raymond A. Geiger
8th Street & North Valley Forge Road, P. O.
Box 309
Lansdale, PA 19446-0309
215-855-0341

Gem-Dandy, Inc.
P.O. Box 657
202 E. Murphy Street
Madison, NC 27025
919-548-9624

Gemini Industries Inc.
Mr. Boyle, Assist VP Eng.
215 Entin Road
Clifton, NJ 07014
201-471-4425

Gendron, Inc.
Frederic W. Strobel, VP Operations
PO Box 197 Lugbill Road
Archbold, OH 43502
419-445-6060

General Dynamics/SSD
Elane Briggs
5001 Kearny Villa Rd.
MZ K1-7146
San Diego, CA 92123

General Service Administration
Debbie Hogan
Telecommunication Division
4KMP
401 W. Peachtree Street
Suite 2700
Atlanta, GA 30308

General Dynamics
Pomona Division-Navajo Facility
Box 679
Ft. Defiance, AZ 86504
602-729-5711

General Electric
Walter R. Guenthes
1 Lakeville Ave.
Burlington, VT 05401

Georgia Tech Research Institute
Melanie Largin
Georgia Institute of Technology
1 Reservation Street
Rome, GA 30161
404-295-6008

Gerber Garment Technology, Inc.
See CMS Division
Gibson, Dunn & Crutcher Lawyers
Sue Unger, Librarian
1050 Connecticut Avenue, N.W.
Washington, DC 20036-5303
202-955-8500

Gibson, Dunn & Crutcher
Attn.: Mr. Erin Mack
1050 Connecticut Avenue, N.W.
Suite 900
Washington, DC 20036

Giddings & Lewis
Margaret M. McMahan, Production
Development, Secretary
Integrated Automation
17801 Fourteen Mile Road
Fraser, MI 48026
313-293-300

Gips Manufacturing Company
P.O. Box 100
401 Randall Street
Hartwell, GA 30643
404-376-8001

Glen Raven Mills, Inc.
T. Marett
Custom Fabrics Division
Equinox Plant
200 Jackson Street
Anderson, SC 29621

Glendale Adventist Medical Center
Jean Ehret
600 South Glendale Avenue
Glendale, CA 91205-2316
818-502-2050

Global Wulfsberg Systems
Gary Levesque
6451 Air Park Drive
Prescott, AZ 86301
602-445-5711

Granite Knitwear Corporation
Attn.: Robert Wade
P.O. Box 498
Granite Quarry, NC 28072-0498

Grant City Manufacturing Corporation
Old Highway 169 North
Grant City, MO 64456

Great West Casualty Company
Orin Selby, Manager, Office Facilities
1100 W 29th Street
P.O. Box 277
South Sioux City, NE 68776
402-494-2411

Greenfield Industries, Inc.
PO Box 2587
Augusta, GA 30913
404-863-7708

Grizzard Advertising Inc.
Human Resourses
1144 Mailing Avenue, S.E.
Atlanta, GA 30315

Gross Galesburg Co.
Richard A. Linville
2900 W. Main St.
Galesburg, IL 61401
309-343-1191

GTE Glass Products
Candace M. Clark
1 Jackson Street
Wellsboro, PA 16901

Gunn, Richard
2341 Chestnut Springs Trial
Marietta, GA 30062
404-578-4891
404-395-4973

Hag, Inc.
Mile Lonergan, VP Sales & Marketing
108 Landmark Dr.
Greensboro, NC 27409
919-668-9544

Haggar Apparel Company
Elaine Moore
6113 Lemmon Ave.
Dallas, TX 75209
214-956-0438

Hampshire Hosiery, Inc.
Denise O. Pittman, Office Manager
PO Box 528
Spruce Pine, NC 28777
704-765-9011

Hamrick Mills
PO Box 48
515 W. Buford St.
Gaffney, SC 29340
803-489-4731

Harbor Resources, Inc.
Dixie Ashburn
900 Circle 75 Pkwy.
Suite 205
Atlanta, GA 30339

Harland Company
Sid Berkstresser
Industrial Engineering Department
P.O. Box 105250
Atlanta, GA 30348
404-981-9460

Harris Manufacturing, Inc.
112 S. Main Street
Smyrna, DE 19977

Harris / RF Communications
Jean Randolph, Medical Dept.
1680 University Ave.
Rochester, NY 14610
716-244-5830 X3496

Hart Schaffner & Marx
Donald Shorr
101 North Wacker Drive
Chicago, IL 60606
312-372-6300

Harvard Industries
Gene Robinson - St. Louis Diecasting Division
201 Rock Industrial Park Drive
Bridgeton, MO 63044
314-291-3700

Haworth, Inc.
Joe Zobkiw
One Haworth Center
Holland, MI 49423-9576
616-393-3000

Haworth, Inc.
Elenore Morris, Plant Secretary
640 River Street
Allegan, MI 49010

Hazcon Inc.
4636 E. Marginal Way, South Ste 215
Seattle, WA 98134
206-763-7364

Health & Safety Department, ILGWU
275 7th Avenue, 6th Floor
Attn.: Nelsa Williams
New York, NY 10001

Hedger, Rose Mary
1120 W. Walnut
Kankakee, IL 60901

Helios Container Systems, Inc.
Attn.: Margo Kapsalis
251 Covington Drive
Bloomingdale, IL 60108

Henricksen Complete Office Interiors
Christine-Marketing
1070 W. Ardmore Ave.
Itasca, IL 60143
708-250-9090

Hercules Incorporated
Kenvil, NJ 07847

Herman Miller, Inc.
Attn.: Gretchen Gscheidle 0440
8500 Byron Road
Zeeland, MI 49464-9399
616-772-3300

Herron, R.E.
1916 Navajo Drive
Fort Collins, CO 80525

Hill-Rom
Karla Shoemaker
Ritter Plant, Hwy. 46
Batesville, IN 47006
812-934-7554

Hillshire Farm & Kahn's
PO Box 227
New London, WI 54961
414-982-2611

Hist. Regency Crown Center
Ann Lawrence
2345 McGee St.
Kansas City, MO 64108

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Freehold, NJ 07728
908-462-3967

Hoechst Diafoil
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Greer, SC 29652
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Hoechst Celanese
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Hoechst Celanese
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Ms. Jo-Ann Benlain, Asst. to Jeff Hollander, Sr. VP Mfg.
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Hollander Home Fashions Corp.
Jo-Ann Benlian, Asst. to Jeff Hollander, Exec. VP
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407-997-6900

Hollowick Inc.
Alan Menter, President
PO Box 305
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Holly Milk
Rosemary Giancoli
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Hollytex Carpet Mills, Inc.
Jim Harris, Personnel Supt.
PO Box 585, Highway 33
Watonga, OK 73772
405-623-7356

Home Insurance Company
William Keppel
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Atlanta, GA 30348
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James Siels
60 John St., 20th Floor
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212-530-7477

Home Insurance Co.
Michael K. Horne, Service Specialist
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Charlotte, NC 28233
704-364-2200

Home Insurance Company, The
Attn.: T. C. Hibbard
Loss Control Department
20th Floor
New York, NY 10038
212-530-6918

Home Insurance Company
Donald J. Jackson, Manager
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80 Pine Street
New York, NY 10005

Homelite Textron
Lynn C. Welborn, Section Mgr, Ind Eng Little Mountain Rd
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704-864-4571

Honeywell
Defense Avionics Systems Division
9201 San Mateo Blvd., NE
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Horton Manufacturing Co., Inc.
Mary Lou Shutt
26837 Industrial Ave.
PO Box 368
Webster, WI 54893
715-866-4298

Howmet Corparation
Wichita Falls Casting Division
6200 Central Fwy
Wichita Falls, TX 76307

HRH Insurance
Irwin C. "Pat" Adams, CSP, VP Loss Control
7 East Congress Street
PO Box 9966
Savannah, GA 31412
912-238-2740

Hudson, Skipper
PO Box 3596
117 Sara Lee Drive
Eatonton, GA 31024

Huisken Meat Center
Maryann Vander Beek
521 N. 5th Street, PO Box 38
Chandler, MN 56122

Hutchinson Bag Corporation
PO Box 1286, 215 S. Poplar
Hutchinson, KA 67504
316-663-8301

Hyperion Seating Corp.
Bonnie Warner
1801 Childress Rd.
Lewisburg, TN 37091
615-359-1190

IMCARE
Betty King
1101 Vermont Ave, NW, Suite 500
Washington, DC 20005

Independent Stave Co., Inc.
Mr. Chris Rash, Benefits, Coordinator
1078 South Jefferson
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Indiana Precision Technology, Inc.
400 West New Road, PO Box 668
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317-462-3015

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Diamond Bldg.
1100 Superior Ave.
Cleveland, OH 44114

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San Francisco, CA 94111

Ingersoll-Rand Co.
Lisa M. O'Dell
PO Box 1776
Liberty Corner, NJ 07938
908-647-6000 ext. 351

Institute of Occupational Health/Library
Ritva Heiskanen, Librarian
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Intel Corp.
Snari Stover
5200 N.E. Elam Young Parkway
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International Ladies' Garment Workers' Union
See "Health & Safety Dept., ILGWU

Intersan Manufacturing Co.
Curtis M. Janney, Nat'l Mktg. Mgr.
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Interthor
1817 Beach Street
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895 Beacon Street
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Islinger, Joseph H.
116 N. Kenilworth
Mt. Prospect, IL 60056
708-577-9535

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Technical Research Services Unit
Hartford Plaza
Loss Control Dept. Library
Hartford, CT 06115

J.A. Majors Company
8723 Knight Rd
Houston, TX 77054-4405
713-795-5599

J.M. Ney Company, The
Ney Industrial Park
Bloomfield, CT 06002

J.P. Stevens & Co., Inc.
Tom McCall, Training Mgr.
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19320 Airbase Road
PO Box 388
Wagram, NC 28396

J. Schoeneman Inc.
643 Middle Street
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Jacobs Engineering Group Inc.
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Charlotte, NC 28217

Jaeger, Bill
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Jefferson Smurfit Corp & Container Corp of America
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Joseph Campbell Company
Michael W. Maxwell, Mgr.-Safety & Training
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Jostens, Inc.
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Laurens, SC 29360

JPS Converter & Industrial Corp.
Jo Banner, RN, OHN
Boger City Plant
2130 East Main Street
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Lincolnton, NC 28093-0658
704-735-2581

Judges' Library
Michelle Seo
Room 5518
US Court House
Washington, DC 20001
202-535-3400

Kap III, Inc.
Kotz A. Patterson, Mgr/Owner
PO Box 404
Henderson, TN 38340
901-989-5749

Kappler USA
Gail Helms, Engineer
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Guntersville, AL 35976
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Kellwood Company
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529 South Broadway
McComb, MS 39648

Kemper National Insurance
Jean Meinhardt
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Long Grove, IL 60049

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Healthcare Products Co.
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1500 Spring Lawn Ave.
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Kuppenheimer Men's Clothiers
Michael L. Love, Director of Projects
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5720 Peachtree Parkway
Norcross, GA 30092-7309
404-449-5877

Kwikset Corp.
516 E. Santa Ana St.
PO Box 4250
Anaheim, CA 92803-4250

La Mar Manufacturing Co.
Rita Daniel, Engineering Dept.
Bowdon, GA 30108

Lakeview Medical Center
1040 Lakeshore Dr
Rice Lake, WI 54868
715-234-1515

Lands' End
Virginia K. Welsh
705 So. Pine Street
West Union, IO 52175

Langhorne Carpet Company, Inc.
Steve Souder
PO Box 7175
Penndel, PA 19047-0824
215-757-5155

LASC
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Lay Packing Co., Inc.
Ruble L. Smith
PO Box 2447
Knoxville, TN 37901
615-546-2511

Lebanon Valley Offset
Carol L. Edris, Dir. Human Resourses
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717-867-4601

Lee Company
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Merriam, KS 66202

Lerner, Al
154 Avenue E
Bayonne, NJ 07002

Leshner Mills
Harmon King
1534 First Ave
Opelika, AL 36801
205-745-6421

Levi Strauss & Co.
R & D Center
900 N. Dorothy Dr.
Richardson, TX 75081

Levi Strauss & Co.
1359 Lomaland
El Paso, TX 79935

Lewis-Gale Clinic
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Lincoln Electric Co.
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Douglas Williams, Industrial Engineer
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Lockwood Green Engineers, Inc.
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LORAL Command & Control Systems
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Lord Corp
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M. J. Soffe Company, Inc.
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Mack Trucks, Inc.
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Magid Glove
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Receiving Dock #4
Howard Systems
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Austin, TX 78762

Mallory Controls
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Mamiye Bros, Inc.
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Management Services, Inc.
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Marathon Electric
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Marion Merrell Dow Inc
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Mine Safety Appliances Co.
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Murrysville, PA 15668-1753

Modernfold Inc.
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Patricia A. Greenlee, Supervisor Benefits Admin.
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New Era Cap Co., Inc.
Michael Williams, Accounts Payable
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Derby, NY 14047-0208
716-549-0445

Newport News Shipbuilding & Dry Dock Co.
The Library
4101 Washington Ave.
Newport News, VA 23607-2770

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PO Box 308
Indiana & Morrow St.
Topeka, IN 46571

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Hawthorne, CA 90250

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OSHKOSH B'GOSH, Inc.
Ms. Sandy Stearns
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Overhead Door Corp

Owen Supply, Inc.
P.O. Box 2098
Fayetteville, NC 28302-2098

Pal Health Technologies, Inc.
Terry Cordum
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Palm Beach Tailored Clothing
PO Box 1519
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Panama Canal Commission
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Cumming, GA 30130
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Panero Zelnik Associates
Martin Zelnik
242 West 27 Street, 1-B
New York, NY 10001
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Peachtree Physical Therapy
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Atlanta, GA 30309

Peck Foods Corp.
200 Emmber Lane
Milwaukee, WI 53233

Pekar, Dennis
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The Pennsylvania State University
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Arleen Rissner
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Kendallville, IN 46755
219-347-5828

Pent Assemblies, Inc.
Steve Hankins
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Perdue University Libraries
Fiscal Dept., Room 264
1536 Stewart Center
West Lafayetta, IN 47907-1536

Perry Printing Corp.
575 West Madison St.
PO Box 97
Waterloo, WI 53594-0097
414-478-3551

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Petri Baking Products, Inc.
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Silver Creek, NY 14136
716-934-2661

Pfizer Inc.
Vigo Plant
Box 88
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Phifer Wire Products, Inc.
Receiving Dept. P.O. # 107224000
440 Kauloosa Ave. at Cole Dr.
Tuscaloosa, AL 35401-7042

Philips Ind.
Jim Burridge
C/O Dextor Axle
222 Collins Rd.
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Philips Lighting
Box 6800
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Platt Luggage
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POP Fasteners
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Powderhorn Textiles
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Powell, Goldstein, Frazer & Murphy
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Pratt & Whitney
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Pretty Products, Inc.
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Queen Carpet Corp.
Bill Kuzwiak
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Quick Rotan, Inc.
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Elmhurst, IL 60126

R. B. Apparel, Inc.
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305-691-8857

R. R. Donnelley & Sons Co.
Daniel J. O'Reilly, Sr. Industrial Hyg.
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Raypak, Inc.
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Rector Sportswear Corporation
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Red Wing Shoe Company, Inc.
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Reeves Brothers, Inc.
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Margaret G. Barber
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Woolrich, Inc.
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APPENDIX B

PUBLICATIONS

PUBLICITY OF ERGONOMICS RESEARCH
1990-1992

Information about the research was the subject of two news releases, the first in April of 1990 and the second in May of 1991. The first release generated placements in publications with a total circulation of 2,127,151, while the second release generated articles with a total circulation of 4,675,737. This includes media placements that our clipping service has found, though there my be others that have not come to our attention.

Together, the two releases have resulted in placements with a total circulation of 6,802,888.

AMERICA'S TEXTILES INTERNATIONAL 08/01/91 ERGONOMICS	32,309	Story
APPAREL INDUSTRY 07/00/90 ERGONOMICS	18,600	Story mention
AREA DEVELOPMENT 08/01/91 ERGONOMICS	36,500	Story
ATLANTA JOURNAL CONSTITUTION 07/23/90 ERGONOMICS	505,372	Story mention
ATLANTA JOURNAL CONSTITUTION 07/23/90 ERGONOMICS	438,000	Story mention
CHICAGO TRIBUNE 08/05/90 ERGONOMICS	774,000	Story
CHICAGO TRIBUNE 06/09/91 ERGONOMICS	1,141,544	Story mention
DAILY NEWS RECORD 09/20/91 ERGONOMICS	24,000	Story mention
DAILY NEWS RECORD	24,000	Picture

06/13/90		
ERGONOMICS		
DAYTON DAILY NEWS	190,437	Story
08/06/90		
ERGONOMICS		
FACILITIES DESIGN & MANAGEMENT	30,000	Story & Picture
02/01/92		
ERGONOMICS		
FORT LAUDERDALE SUN SENTINEL	262,011	Story mention
06/17/91		
ERGONOMICS		
INDUSTRIAL ENGINEERING	47,500	Story
06/00/91		
ERGONOMICS		
INDUSTRIAL FABRIC PROIDUCTS	10,000	Story
08/01/91		
ERGONOMICS		
INDUSTRY WEEK	288,000	Story & Pictures
10/07/91		
ERGONOMICS		
MACON TELEGRAPH	80,000	Story mention
06/17/91		
ERGONOMICS		
MANUFACTURING ENGINEERING	130,000	Story mention
11/01/91		
ERGONOMICS		
MANUFACTURING SYSTEMS	115,000	Story
11/01/91		
ERGONOMICS		
MODERN PAINT & COATINGS	14,000	Story
08/01/91		
ERGONOMICS		
OCCUPATIONAL HEALTH & SAFETY NEWS		Story
11/22/91		
ERGONOMIC STUDY		

SAFETY & HEALTH 12/00/90 ERGONOMICS	35,000	Story
RIVERSIDE PRESS ENTERPRISE 08/18/91 ERGONOMICS	170,000	Story mention
SAN JOSE MERCURY NEWS 06/12/91 ERGONOMICS	280,918	Story mention
ST. PETERSBURG TIMES 06/10/91 ERGONOMICS	389,924	Story
TAMPA TRIBUNE 07/30/90 ERGONOMICS	275,000	Story
TAMPA TRIBUNE 05/14/90 ERGONOMICS	275,000	Story brief
THE WASHINGTON POST 06/16/91 ERGONOMICS	1,165,567	Story mention

APPENDIX C

PHASE I: ERGONOMIC SURVEY IN THE MANUFACTURING WORKPLACE

DESIGN AND DEVELOPMENT OF A SELF STUDY COURSE FOR APPAREL SUPERVISORS IN THE PRACTICAL APPLICATION OF ERGONMIC PRINCIPLES

PHASE 1 REPORT: ERGONOMIC CONSIDERATIONS IN CONVENTIONAL TROUSER MANUFACTURING

Research Sponsored by:

U.S. Defense Logistics Agency

Daniel J. Ortiz, Principal Investigator
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Georgia Tech Project A-8311

Georgia Institute of Technology
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March 1989-September 1989

TABLE OF CONTENTS

TABLES AND FIGURES

ABSTRACT

In order for the apparel industry to maintain and improve its competitiveness in the world marketplace, it must adopt many emerging technologies and achieve the maximum benefit from them. During the transition to a high technology manufacturing environment, jobs and workplaces should be designed to promote employee productivity, comfort and safety. Design of jobs and equipment to match the physical and mental characteristics and limitations of the equipment operators is the goal of the science of ergonomics.

Georgia Tech is conducting a two-year program to explore ergonomics issues in typical trouser manufacturing plants in the Southeast, to test cost-effective solutions to these problems, to predict and address ergonomics issues in the high technology apparel manufacturing environment, and to develop training and reference materials that will allow plant managers and supervisors to solve basic ergonomics problems on their own.

During Phase 1 of the program, interviews were conducted with over 120 operators in three typical trouser manufacturing plants in the Southeast. These interviews covered work-related injuries and musculoskeletal discomfort, job and workstation design, training, work schedule, and other job factors. A set of relevant body measures was taken of this group of workers. Measures of lighting, noise and temperature were made at sewing workstations in the three plants. Videotapes were made of skilled and novice workers performing certain key operations for later motion analysis.

This report provides a summary of the findings of these investigations including comparisons of the anthropometric data with other available data bases, summaries of the data on musculoskeletal discomfort and implications of the identified patterns, discussions of the physical working environment, descriptions of operator training methods, and recommendations for workstatio and job improvement. A discussion of preliminary findings concerning applications of advanced manufacturing technology is also included.

1. BACKGROUND AND OBJECTIVES

In order for the United States apparel industry to maintain and improve its competitiveness in the world marketplace, it must adopt emerging manufacturing technologies and achieve the maximum benefit from them. During the transition to a high technology manufacturing environment, jobs and workplaces should be designed to promote employee productivity, comfort and safety.

Ergonomics (the study of the physical and mental characteristics and limitations of workers and the design of jobs and equipment to take these factors into account) has been effectively applied in many working environments. These include transportation, health care, mining, textile manufacturing, and a host of others. For various reasons, the practice of ergonomics or, alternatively, human factors engineering, has not been extensively applied in the apparel manufacturing environment.

Under the two-year program, Georgia Tech is exploring human factors problems in typical trouser manufacturing plants in the Southeastern United States and identifying and testing cost-effective interventions for the uncovered problems. Lessons learned from this initial exploration will be used to predict and address related human factors issues in the apparel factory of the future as represented by the Apparel Manufacturing Technology Center. In the final phase of the program, training documentation will be produced to assist supervisors, middle and upper management in recognizing and solving typical human factors problems.

Trouser manufacturing, whether in a conventional or high-technology workplace, is a highly labor-intensive process with 20 or more distinct steps. Each of these steps involves the operation of one or more kinds of power equipment such as specialized cutting and sewing machines. The steps require significant amounts of manual manipulation of fabric bundles, individual pieces, and unfinished garments as they are transported, inserted into, and guided through the machines. The operations are highly repetitive and visually demanding.

Repetitive, hand-intensive work may result in health problems such as cumulative trauma disorders (CTDs) that increase absenteeism and reduce productivity. One such disorder is carpal tunnel syndrome (CTS), a compression neuropathy involving the median nerve that provides sensation to a large portion of the hand. Occupational risk factors associated with CTS include repetitive movement of the hand, non-neutral wrist postures, and forceful exertions. The disease is characterized by pain and numbness in the hand and wrist, and it has been found to be common among manufacturing workers.

The objective of the initial phase of the project, on which this report is based, was to collect anthropometric and background data on existing conventional manufacturing workplaces and worker populations. In support of this effort, an extensive literature review was conducted. Literature consulted for this phase has been combined into a reference bibliography in Appendix A. Our interviews and measures were specifically designed to elicit information valuable for (1) identifying and solving current, conventional manufacturing problems, (2) identifying areas of the conventional environment that should be candidates for automation, and (3) predicting human factors related issues likely to appear in the advanced manufacturing environment.

The principal objective of this program is to develop a comprehensive set of specially tailored ergonomics training and reference materials that will help apparel manufacturing supervisors and management (1) identify workplace tools, layouts, and procedures that are incompatible with the characteristics and limitations of the workforce, (2) identify options for addressing the identified problems, and (3) choose and implement ergonomically appropriate solutions. The materials will specifically address ergonomic aspects of conventional and advanced manufacturing environments in which trousers are produced.

Careful design of workplace tools and equipment requires the engineer to obtain and apply data on the relevant physical dimensions of the worker population. Such data, however, are not readily available for most populations. A decade ago, Van Cott (1980), an ergonomist with the National Bureau of Standards, lamented that "civilian anthropometry data bases in the United States and other countries are virtually nonexistent." Casey (1989) noted that, during the 1980s, the availability of such data has become even worse. Casey demonstrated that for one worker population, farm equipment operators, existing data bases provide an extremely inaccurate model of the user group. During Phase 1, we obtained relevant measures of a large number of apparel manufacturing operators to compare with the few existing anthropometric data bases and also to provide designers an additional resource.

A second task was to identify problems related to workplace and job design in typical conventional apparel manufacturing operations, including those in transition to an advanced technology environment. These problems were identified through a combination of employee interviews and direct observation and measurement. Employee interviews were used to identify symptoms of workplace difficulties as well as the operators' perceptions of these difficulties and potential methods of improvement. Direct observation and measurement through the use of videotaping and physical measurement of relevant environmental characteristics were used to allow us to document and verify the nature and magnitude of the recognized (or as yet unrecognized) problems.

During Phase 2 of the program, we will test interventions that address some of the difficulties we have identified. During Phase 3, research will move into the high-technology manufacturing environment to address potential human factors problems. During Phase 4, we will produce a set of training materials to allow supervisors and middle and upper management to understand and address human factors issues in their workplaces.

2. METHODS

Site visits were conducted at three plants that manufacture trousers and are located in the Southeast. These plants were selected to provide a range of company sizes and degrees of automation that is typical of the industry. The numbers of workers employed by the three plants ranged from 50 to 600. Two of the three produce only military uniform trousers while the third produces a range of dress and casual trousers.

Employees in the jobs selected for video analysis were given the first opportunity to volunteer for interview and measurement sessions. Participation was then opened to all other employees. Interview and measurement sessions were held before work, after work, and during the lunch break and required approximately 30 minutes of each participant's time. Participants were paid for their time.

A total of 132 operators (123 female and 9 male) were interviewed and measured during the research. Interview data from two female operators was deleted because of language difficulties and job type. However, both subjects' measures are included in the anthropometric data base. The male data was not analyzed because of the small subject population. The "typical" female who participated in this study was forty years old with 103 months experience. Significantly, sixty-four percent of the female population was at least forty years old.

2.1 ANTHROPOMETRIC MEASURES

Anthropometric measures were taken on all interview participants. Subjects were measured in each of ten dimensions related to workstation and operator interface. The dimensions were selected for the following applications: cross-referencing (stature), work surface and display height (eye height, shoulder height, elbow height, and seated height), reach distances (arm length), seating characteristics (seated height, thigh clearance and popliteal height), and tool design (hand length and hand breadth).

Due to time and logistics constraints, the measuring apparatus utilized was portable and consisted of a GPM Model 101 anthropometer with baseplate and GPM Model 106 spreading caliper both graduated to whole millimeters. All measures were taken with shoes removed. Subjects were measured in their own clothing. Clothing was typically of a lightweight, summer type (e.g., shorts, t-shirts, cotton skirts, etc.). For standing measures subjects stood erect, facing forward. For seated measures, subjects sat erect on a flat surface. For shoulder height, elbow height, arm length, thigh clearance, popliteal height, hand breadth, and hand length, the subjects were measured consistently on the right hand side.

Measures were defined as follows:

1) Stature - Vertical distance from the floor to the crown of the head, measured with the subject standing. Subject was asked to report when the bar was felt on the top of head (as opposed to touching the hair) to confirm contact.

2) Eye height - Vertical distance from the floor to the inner canthus (corner) of the eye, measured with the subject standing.

3) Shoulder height - Vertical distance from the floor to the acromion, measured with the subject standing.

4) Elbow height - Vertical distance from the floor to the radiale (upper end of the radius), measured with the subject standing.

5) Arm length (Upper limb length) - Distance from the acromion to the fingertip with the arm fully extended parallel to the floor.

6) Seated height - Vertical distance from the sitting surface to the crown of the head. Subject was asked to sit up straight and, as with stature, report bar contact with the top of the head.

7) Thigh clearance - Vertical distance from the sitting surface to the top of the thigh tissue at its thickest point, typically (though not in all cases) where it met the torso.

8) Popliteal height - Vertical distance from the heel to the popliteal crease behind the knee.

9) Hand length - The distance from the wrist landmark (crease) to the dactylion (tip of middle finger).

10) Hand breadth - The distance between the second and fifth metacarpal-phalangeal joints.

2.2 INTERVIEW

Detailed interviews were conducted with all participants using a structured interview (form included in Appendix B). The participants (interviewees) were assured that their responses would be held confidential, and their names were not placed anywhere on the interview forms. To the extent possible, interviews were held in closed offices or in areas isolated from other employees to encourage candor in the responses. The interviews covered:

1) Demographic information
2) Work related injuries or musculoskeletal discomfort
3) Characteristics of the work environment
4) Characteristics of the workstation, chair, and job
5) Training
6) Work schedule
7) Other factors that might affect safety or productivity

During interview sessions, as many as three interviews might be occurring simultaneously in order to complete the large number of required interviews in the limited available time. To promote uniformity among the interviewers, most of the interview consisted of YES/NO, multiple choice, or short answer questions. The final two questions, however, were open-ended and the interviewer attempted to draw out more detailed information on previous interesting responses or suggestions on how the jobs might be improved.

Responses to interview questions were manually entered into a computer file for statistical analyses.

2.3 WORKSTATION MEASURES

Thirty individuals representing the fourteen jobs listed below were selected for video analysis. These jobs were "targeted" since they satisfied one or more of the following criteria based on discussions with supervisors, managers, and engineers: (1) job is in high skill category based on productivity and training measures; (2) job has a history of CTDs; (3) job has a high level of absenteeism and/or complaints.

BUTTON HOLE	FLY LINING
PATTERN STITCH	POCKET WELT
SIDE SEAM	TRIMMING
SIDE AND INSEAM	SEAT SEAM
LEFT FLY	RIGHT FLY
SET AND CORD POCKETS	FACE AND CLOSE POCKETS
SLIDE AND STOP	TACK FRONT POCKETS

Of the jobs above, only trimming had a *documented* case of carpal tunnel syndrome in the past two years. Trimming, pocket welt, and slide and stop were standing workplaces (N = 5). The remaining jobs were performed in the seated work posture (N = 25). Where possible, two employees with different levels of experience were videotaped at each of the target jobs. Front, side, and back views were taken and analyzed using a computer video registration and analysis (VIRA) method described by Keyserling (1986) and Melin (1987) in the scientific literature. Videotape was reviewed in slow motion and the duration of time spent in each of four hand postures (dorsiflexion, flexion, ulnar and radial deviation) was documented for every subject. A posture change was noted when the hand movement resulted in at least a 15 degree departure from the neutral. Pinching (lateral and pulp pinches) and flat hand presses were also documented using this method. The number of posture changes was documented for each posture category as well. Back and neck angles were measured with the use of a protractor.

At each workstation selected for videotaping, measures of critical workstation dimensions were taken. Measures were taken both to support later video analysis and to provide a comparative dimensional baseline for use with anthropometric data in workstation evaluation. A metal tape measure was utilized for all linear measures. Basic dimensions selected included:

Work surface height, length, and width

Length and width of operator's work envelope (estimated)

Distance from the proximal edge of the work surface to the point of operation

Seat height, height including cushions or pillows (compressed), length, and width

Distance from the seat back to the proximal edge of the work surface

Reach distance (estimated) to raw material (e.g., piece on cart)

Reach distance (estimated) to finished material (finished good disposal)

Treadle location relative to work surface (plan view)

Treadle length, width and height

Cart or clamp truck dimensions

Location of obstructions where noted

Those measures indicated as estimated were taken using the tape measure to estimate the dimension reported in order to prevent interference with production. Work envelope was defined as the total travel area of the operator's hands during the course of operation on a piece or garment. It did not include initial reaches to obtain the work piece or reaches to dispose of finished work. Reaches to raw and finished materials were measured from the operator's proximal shoulder to the grasp at the point of acquisition or release.

The workstation physical assessment also included measures of the weight of the work piece handled, how many were handled at one time (e.g., if 6-7 pieces were lifted at a time from the supply cart or truck to the operator's lap), the force required to actuate needle movement, and the force required to bring the machine to full operation. Forces and weights were measured using a Chatillon DFG-100 Digital Force Gauge. Any operator comments on workstation attributes were also recorded.

2.4 ENVIRONMENTAL MEASURES

2.4.1 Noise

A general noise survey was conducted at each facility using a General Radio Model 1982 Sound Level Meter (GenRad). The sound level meter was calibrated with a General Radio 1562-A Sound Level Calibrator before and after each survey. A representative sample of plant noise levels was obtained for both ambient noise and noise close to the operators' ears. At locations where the GenRad indicated levels approaching 90 dBA for an instantaneous measure, a Quest Electronics Model Micro 15 Permissible Noise Dosimeter was utilized to further investigate exposures. An employee in each target location volunteered to wear the dosimeter for a full shift.

2.4.2 Illumination

Lighting measurements were taken with a Gossen-Panlux light meter that is both color and cosine corrected to approximate the sensitivity of the eye to different wavelengths. Illuminance readings were taken at most sewing room task locations in each plant. Measurements were obtained with the probe in the horizontal plane close to the workstation point of operation (POO). Generally, two measurements were taken at each workstation: one with and one without the use of supplementary or task lighting (if available). The illuminance values collected were then compared to those recommended by the Illumination Engineering Society of North America (IESNA, 1981) for men's clothing manufacture. The IESNA illuminance categories and target values are based on the average age of the workforce, demand for speed and accuracy, and the background reflectance.

2.4.3 Temperature

A general temperature and thermal comfort survey was conducted at each facility using a Reuter-Stokes Model RSS-211D "Wibget" Heat Stress Monitor. A representative sample of levels was obtained for both dry bulb and wet-bulb-globe temperatures (WBGT) in degrees Fahrenheit.

3. RESULTS

3.1 ANTHROPOMETRY

The anthropometric population for the study totaled 123 female subjects. The population averaged 40 years of age (standard deviation 14 years, range 16-74 years). The mean, standard deviation, and 5th and 95th percentile values for each dimension are reported in Tables 1-3. Additional comparison values are provided from Society of Automotive Engineers publication SAE J833 DEC83 entitled "USA Human Physical Dimensions," MIL-STD-1472C, and HEW National Center for Health Statistics 1960-1962 study.

The following factors should be taken into account when comparing the data:

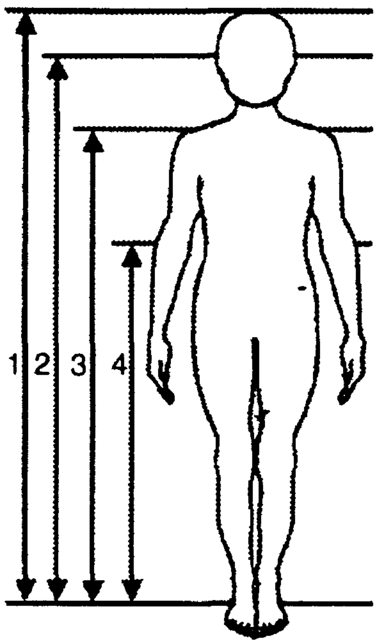
1) The HEW figures listed are taken from the NASA *Anthropometric Source Book*, Volume I—Anthropometry for Designers. It should be noted that the NASA reported figures represent only that part of the population between ages 25-40. The actual HEW study reports figures from ages 18-79. This somewhat limits comparison with the current study population. However, as the NASA document is considered a "good" reference for equipment design, the data is provided for comparison.
2) SAE J833 DEC83, presumably a civilian database, is actually a hybrid composed of both civilian and military data. The level of influence varies depending on the dimension selected.
3) The MIL-STD-1472C data is provided for comparison with female design criteria for military designs.

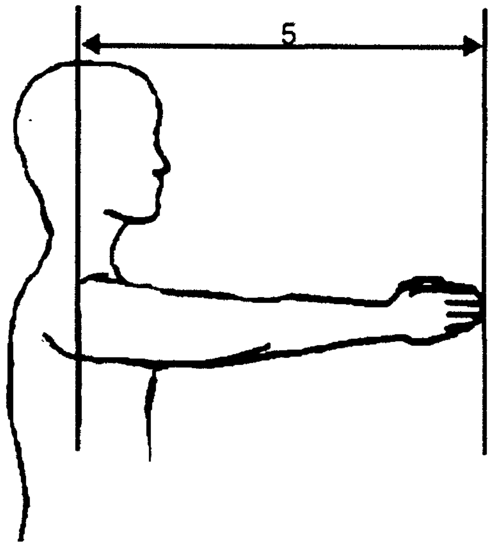
These notes point out the serious lack of current dimensional data for female civilians. As the comparative data provided is excerpted from some of the more commonly utilized design references, the level of potential design contamination due to data from military populations (which tend to have their own particular population characteristics) and limitation of the population age range (which influences distributions) is readily apparent. Designers should consider these factors when utilizing these sources.

3.2 MUSCULOSKELETAL DISORDERS

Based on the available 1988 and year-to-date 1989 OSHA 200 logs, the incidence of cumulative trauma disorders at Plants A and B (total of 4 cases) was approximately 167 cases per 10,000 employees. Plant C did not allow us to review their log information, but one case each of tendinitis, carpal tunnel syndrome, and bursitis was reported during the interview process. When employees at Plants B and C (N = 94) were asked if they experience joint numbness at night, 34 percent responded "yes". Approximately 90 percent of these individuals reported that the numbness involved the hands, wrists, and/or fingers. Since numbness of the hands, particularly at night, is a possible symptom of carpal tunnel syndrome, this finding suggests that the injury/illness records may not accurately reflect the true prevalence of CTS in the workplace. To substantiate this claim would require diagnostic measures and medical interpretation. Four back strains apparently due to bundle or fabric handling were also reported during this period with no detectable job trends.

Table 1. Selected Standing Body Dimensions of Female Apparel Manufacturing Workers





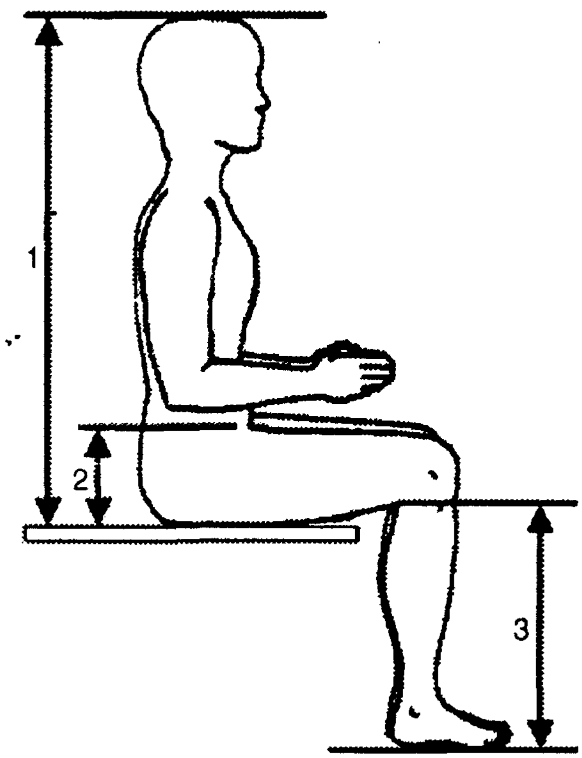
Dimension	Mean	SD	Percentile 5th	Percentile 95th	Source
(1) Stature (cm)	160.7	6.4	150.2	171.2	Current Study
	161.7	6.3	151.3	171.9	U.S. HEW Civilians [a]
	163.3	***	152.4	174.1	U.S. Army MIL-STD-1472C [b]
	160.0	***	150.0	170.4	SAE USA Physical Dimensions [c]
(2) Eye Height (cm)	150.6	6.2	140.5	160.7	Current Study
	***	***	***	***	U.S. HEW Civilians
	151.5	***	140.9	162.2	U.S. Army MIL-STC-1472C
	150.4	***	142.2	158.6	SAE USA Physical Dimensions
(3) Shoulder Height (cm)	133.3	5.9	123.7	143.0	Current Study
	***	***	***	***	U.S. HEW Civilians
	133.3	***	123.0	143.7	U.S. Army MIL-STD-1472C
	132.9	***	123.0	143.4	SAE USA Physical Dimensions
(4) Elbow Height (cm)	103.1	4.5	95.6	110.47	Current Study
	***	***	***	***	U.S. HEW Civilians
	102.8	***	94.9	110.7	U.S. Army MIL-STD-1472C
	***	***	***	***	SAE USA Physical Dimensions
(5) Arm Length (cm)	69.8	3.6	63.9	75.6	Current Study [+]

*** No comparison data available for this characteristic.

[a, b, c] See end of tables (p.) for references

[+] No comparison data available

Table 2. Selected Seated Body Dimensions of Female Apparel Manufacturing Workers

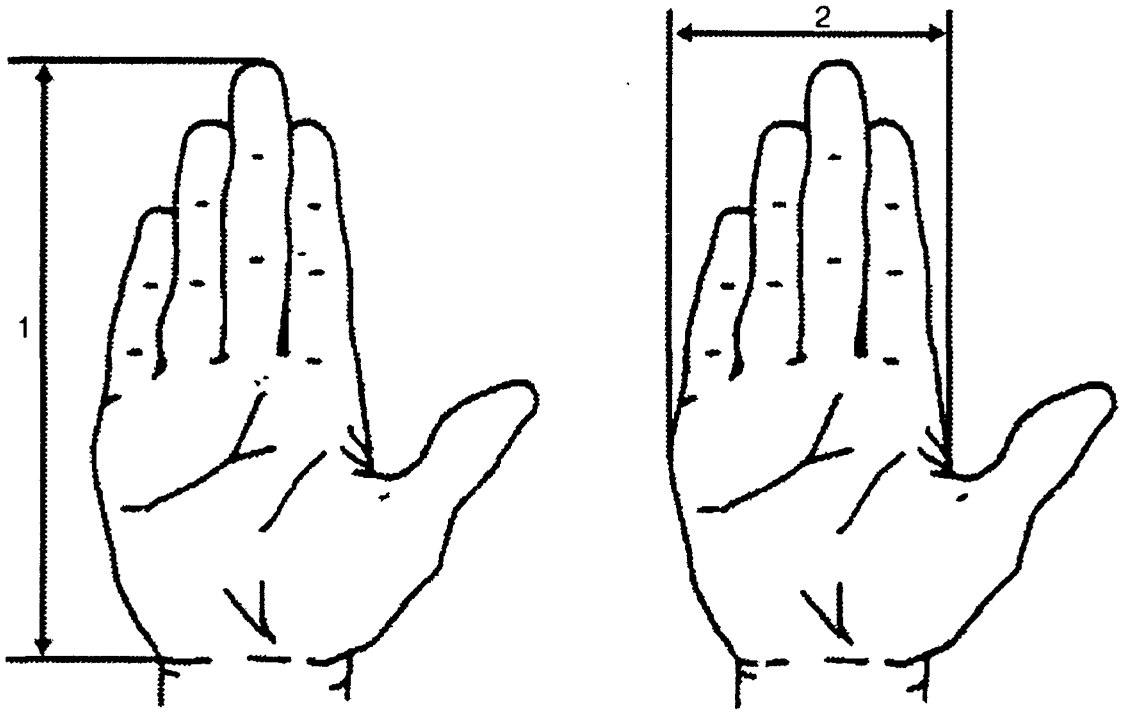


Dimension	Mean	SD	Percentile 5th	Percentile 95th	Source
(1) Seated	84.2	3.5	78.5	90.0	Current Study
Height	85.6	3.3	79.9	91.4	U.S. HEW Civilians [a]
(cm)	85.0	***	79.0	90.9	U.S. Army MIL-STD-1472C [b]
	84.8	***	78.5	90.7	SAE USA Physical Dimensions [c]
(2) Thigh	15.0	2.1	11.6	18.5	Current Study
Clearance	13.9	1.9	10.7	17.8	U.S. HEW Civilians
(cm)	14.0	***	10.4	17.5	U.S. Army MIL-STD-1472C
	13.7	***	10.4	17.5	SAE USA Physical Dimensions
(3) Popliteal	41.7	2.5	37.6	45.8	Current Study
Height	40.0	2.6	35.8	44.3	U.S. HEW Civilians
(cm)	41.8	***	38.0	45.7	U.S. Army MIL-STD-1472C
	39.9	***	35.6	44.5	SAE USA Physical Dimensions

*** No comparison data available for this characteristic.

[a, b, c] See end of tables (p.) for references

Table 3. Selected Hand Dimensions of Female Apparel Manufacturing Workers



Dimension	Mean	SD	Percentile 5th	Percentile 95th	Source
(1) Hand	17.5	.9	16.1	18.9	Current Study
Length	***	***	***	***	U.S. HEW Civilians [a]
(cm)	18.0	***	16.1	20.0	U.S.Army MIL-STD-1472C [b]
	17.9	***	16.1	20.0	SAE USA Physical Dimensions [c]
(2) Hand	7.8	.4	7.1	8.5	Current Study
Breadth	***	***	***	***	U.S. HEW Civilians
(cm)	7.7	***	6.9	8.5	U.S.Army MIL-STD-1472C
	7.4	***	6.9	8.4	SAE USA Physical Dimensions

*** No comparison data available for this characteristic.

[a] Stoudt, H.W., Damon, A., McFarland, P. and Roberts, J. (1965). Weight, height, and selected body dimensions of adults, United States, 1960-1962. *Vital and health statistics, series 11*, No. 8. Washington, D.C.: U.S. Dept. of Health, Education, and Welfare, as cited in:
Webb Associates. 1978. *Anthropometric Source Book, Volume I—Anthropometry for Designers.* (NASA Reference Publication 1024). Washington, D.C.: National Aeronautics and Space Administration. (NTIS No. N79-11734).

[b] Department of the Army. 1981. *Human Engineering Design Criteria for Military Systems*, MIL-STD-1472C. Natick, Mass.: U.S. Army Natick Laboratories.

[c] Society of Automotive Engineers. 1983. *USA human physical dimensions.* SAE J833 DEC83. Warrendale, Penn.: Author.

3.3 POSTURAL DISCOMFORT

Improper job design and badly designed workplaces can often create aches and pains in the muscles and joints of assembly workers. This can result from awkward working postures, excessive reaches to obtain or dispose of work, excessive manual manipulation of parts, excessive strength or muscular endurance requirements, or combinations of these factors. It is possible, therefore, to obtain clues about workplace and job design problems by exploring the patterns of musculoskeletal discomfort experienced by the operators while on or off-duty.

In addition, these data on musculoskeletal discomfort can provide information useful in establishing priorities for automation of particular sewing operations in the advanced technology sewing workplace. Chronic, work-related discomfort is one possible reason for attrition of highly skilled sewing operators as well as a potential cause of absenteeism and lowered productivity. If operations that are particularly stressful to the musculoskeletal system can be successfully automated, or if the conventional workplace can be modified to promote comfort, it will be easier to retain experienced, skilled workers and to maintain their productivity.

One goal of the Phase 1 effort was to document patterns of musculoskeletal injury or discomfort experienced by apparel manufacturing operators and to begin to correlate these discomfort patterns with the job and workplace elements that might be causing them. Using the procedures described in Section 2.2 (Methods), 121 female sewing operators rated the frequency with which they experienced muscular or joint soreness that might be related to their jobs in each of 16 areas of their bodies. Workers were asked to respond that they experience pain in a given area "never," "sometimes," "frequently," or "constantly."

The overall results are shown in Figure 1. Approximately half of all interviewed workers reported that they at least "sometimes" experience pain in their *upper back* (52%), *neck* (49%), and *right hand* (48%). One-third or fewer workers reported that they at least "sometimes" experience pain in their *right arm* (33%), *right leg* (26%), *right foot*, (26%), *right knee* (24%), *left arm* 24%), *left leg* (22%), *left foot* (20%), and *left knee* (17%).

On the bases of observation and of interviews with an experienced methods engineer, the sewing jobs were classified as requiring "low", "medium", or "high" amounts of manual manipulation of materials. High manipulation jobs identified were:

SIDE SEAM	SIDE AND INSEAM
TOPSTITCH	BLINDSTITCH BAND
TOPSTITCH LEFT FLY	ATTACH AND FINISH RIGHT FLY
SEAT SEAM	

Medium manipulation jobs were:

SET FRONT POCKETS	J-STITCH LEFT FLY
SERGE ZIPPERS AND FLIES	REPAIR TOPSTITCH WINGS
BIND BROADFALL	CROTCH PIECE
FACE AND CLOSE FRONT POCKETS	

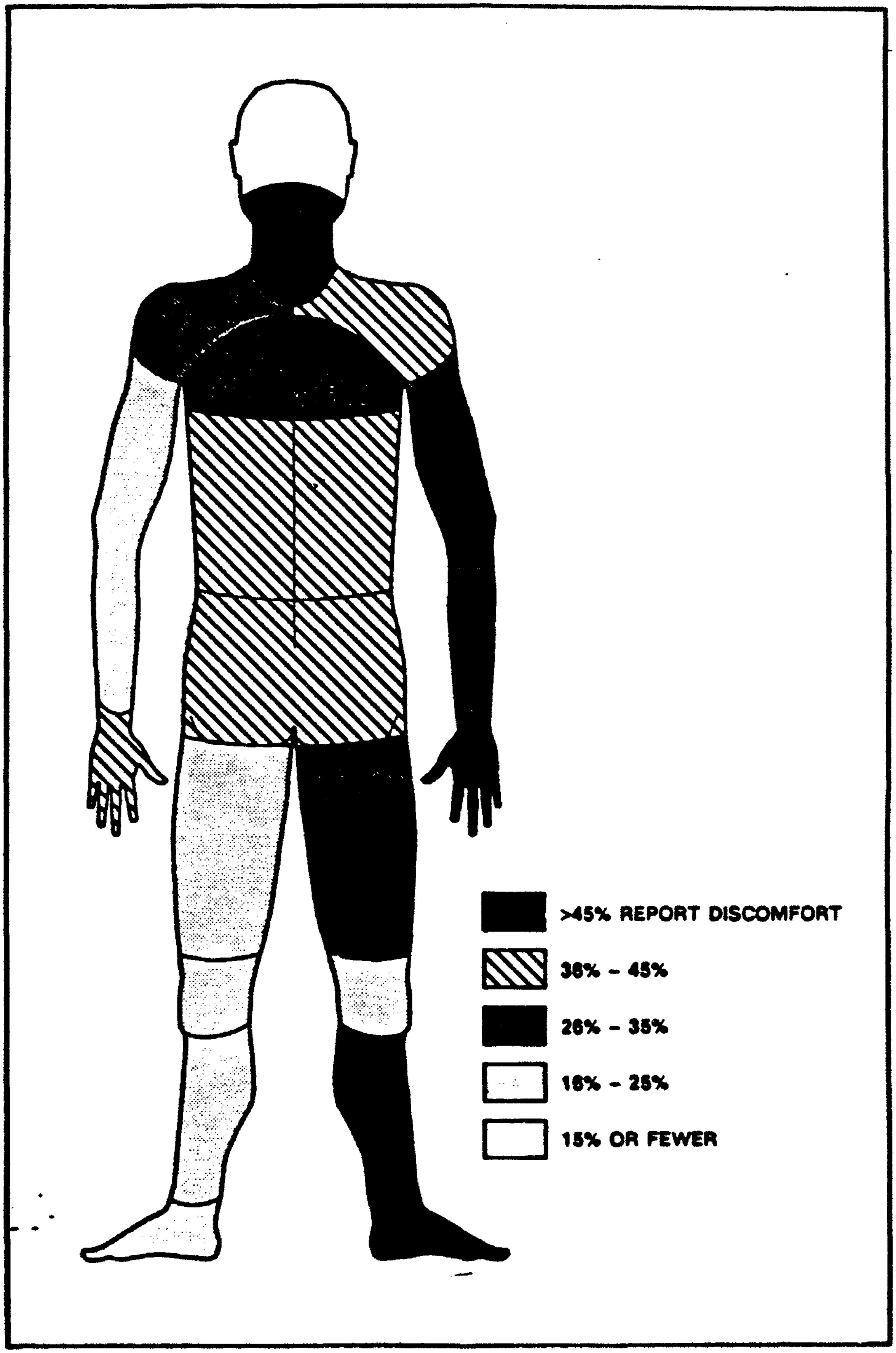


Figure 1. Percentage of Workers Reporting Musculoskeletal Discomfort by Body Area

Low manipulation jobs were:

TOP CORD BACK POCKETS	FACE BACK POCKETS
LABEL BACK POCKETS	MAKE LOOPS
TACK LOOPS	TRIM/INSPECT/SIZE TICKET
TAPE CROTCH	SPLIT BROADFALL
PATTERN STITCH	MARK BUTTON HOLES
EYELETS	FINISH BACK POCKET
ROCAP BANDS	PRESSING
BUTTON WRAP	HOOK AND EYE
SLIDE AND STOP	POCKET WELT
TURN POCKETS	SEW BACK DARTS

Figure 2 demonstrates the differences in discomfort frequencies between low manipulation and high manipulation jobs. Operators in high manipulation jobs reported substantially greater levels of musculoskeletal discomfort overall. Greatest discomfort levels were concentrated in the upper and middle back, neck, right shoulder, and hands. Seventy-three percent of the high manipulation operators reported pain in their right hands, the highest discomfort frequency identified by our analyses. Fifty percent of the low manipulation operators experienced upper back pain, roughly the same percentage as high manipulation operators (54%). In contrast to the general trend, the low manipulation workers reported almost double the frequency of lower back pain (39%) of the high manipulation workers (23%).

While the vast majority of jobs were performed while seated (97 of 121), a smaller number were performed standing (18 of 121) or both seated and standing (6 of 121). Some jobs (e.g., slide and stop and pocket welt) were done while standing at some locations and sitting at others. Figure 3 shows the differences in discomfort frequencies between the seated operators and the standing operators. It is apparent that overall discomfort is markedly less in the standing operations. As would be expected, standing workers reported a higher level of foot discomfort than did the seated workers. Complaints of pain in the back, neck and shoulders, however, were fewer, probably due to the more erect posture used by standing workers. Complaints of hand pain were fewer, probably because the standing jobs, on average, required less manipulation of materials.

An interesting trend was noted in analyses of discomfort frequency by operators of different chronological ages and levels of experience. Reports of musculoskeletal discomfort were most frequent among the relatively young workers (those between the ages of 26 and 35 years) and among those with one to three years of sewing experience. Substantially fewer reports were made by those over 55 years of age and those with over 25 years experience. This trend might be attributed to one or more of several factors. Some of the older workers appeared less willing to discuss their aches and pains, possibly fearing retribution by management. In other cases, older workers had been transferred to less physically demanding jobs. Finally, there is probably a significant amount of self-selection by which workers who are susceptible to musculoskeletal injuries leave this workforce and seek other jobs within the first years of work.

It was expected that we would find a substantial degree of similarity between the three interview sites in the discomfort experienced by the operators. This expectation was supported by the data. For each of the three sites, the 16 areas of the body were ranked according to the frequency with which work-related discomfort was reported at least "sometimes." Spearman Rank Correlation coefficients

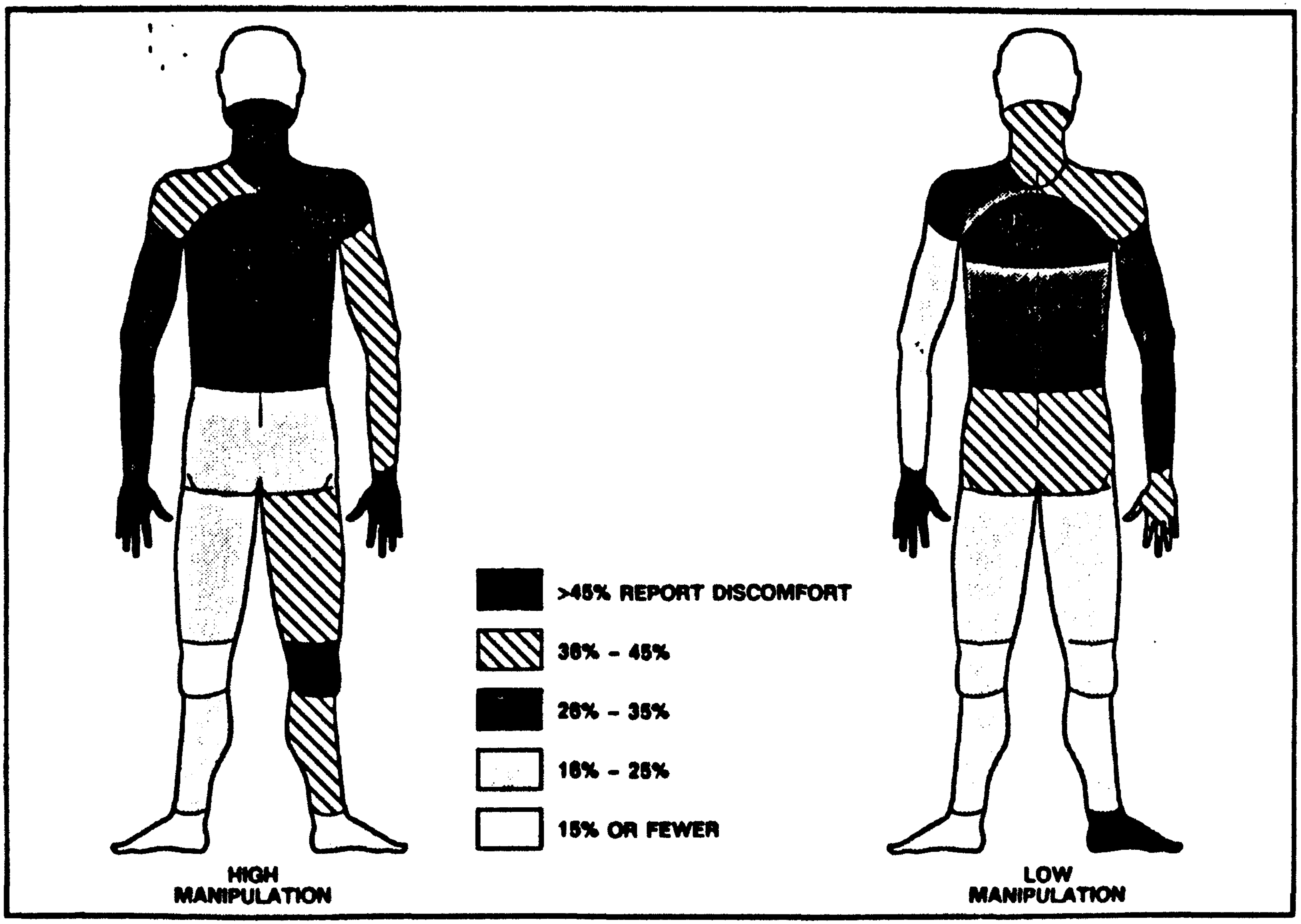


Figure 2. Percentage of Workers Reporting Musculoskeletal Discomfort in High Manipulation and Low Manipulation Jobs

mk.A8311.200.III-2

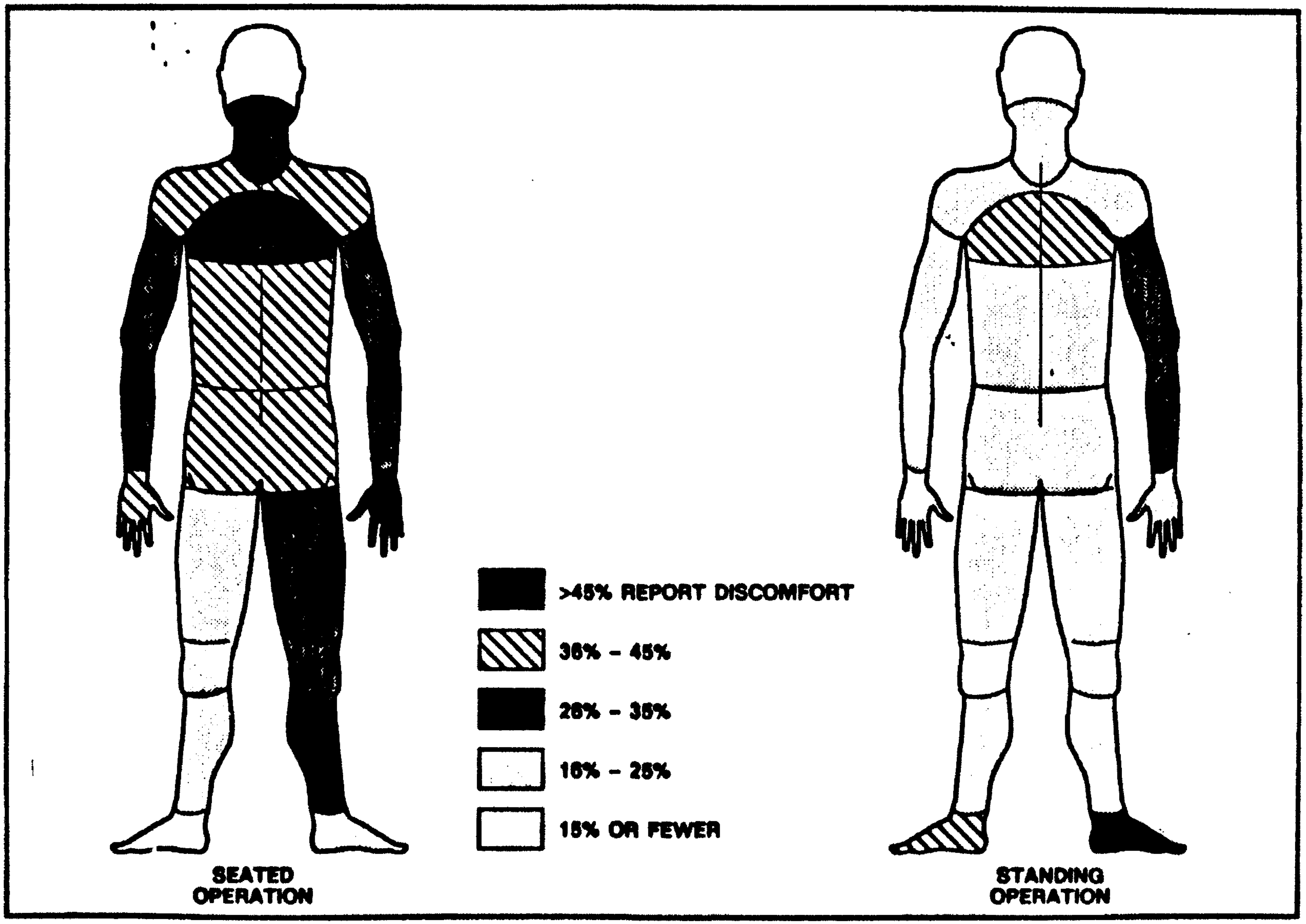


Figure 3. Percentage of Workers Reporting Musculoskeletal Discomfort in Seated and Standing Jobs

mk.A8311.200.III-3

were then calculated between each pairing of the three sites. Table 4 presents the results of these calculations.

TABLE 4. SPEARMAN RANK CORRELATION BETWEEN THREE INTERVIEW SITES OF BODY PART DISCOMFORT FREQUENCY

	SITE A	SITE B	SITE C
SITE A	1.00		
SITE B	.35	1.00	
SITE C	.54 *	.57 *	1.00

* Statistically significant beyond .05 level.

Probably the major difference between data from Site A and data from the other two sites is that there was little indication of hand and wrist discomfort at Site A. At Sites B and C, by contrast, hand pain was the most frequent physical complaint. At Site A, pain in the right shoulder was a major complaint while it was not at Sites B and C.

Site B had disproportionately larger amounts of foot discomfort, possibly because of a larger percentage of standing operations. There were also a larger number of complaints of right arm pain than at the other two sites.

It is important to be aware of the potential limitations on the validity of these body part discomfort data. Self-reports of work-related pain are subject to many biases. First, there are significant individual differences in what is perceived as pain and differences in what kinds of pain are attributed to work-related difficulties. Numerous workers reported discomfort in various parts of their bodies but attributed this to normal aging processes rather than to their jobs. Second, these reports depend on the memory of the operators being interviewed. Recent experiences with discomfort will likely be over-reported while experiences in the more distant past may be over-reported or under-reported. Finally, there may be a reluctance to report discomfort because of a fear of retribution by supervisors (even though workers were assured that interviews were confidential) or out of a sense of loyalty to the organization. Operators at one site seemed especially reluctant to report difficulties of any kind. While working conditions at this site were certainly no better than at the other two sites, both physiological and environmental complaints were substantially lower.

3.4. VIDEO ANALYSIS

3.4.1. Hands

The cycle time of the 14 jobs analyzed ranged from 10 to 109 seconds with most in the 20 to 40 second range. There were an average of 29.9 left and 25.6 right hand posture changes per cycle. Comparing individuals working at the same job with different experience levels shows that experienced employees work significantly faster than employees with less experience. This "working faster" also appears to be associated with greater hand activity per minute. Table 5 summarizes the video registration and analysis results. Duration is the percent of the cycle time spent in each posture category.

TABLE 5. VIRA RESULTS

POSTURE CATEGORY	DURATION Left Hand	Right Hand
Pinch (lateral and pulp)	50.1	54.9
Flat Press	25.7	19.5
Ulnar Deviation	29.5	29.8
Radial Deviation	7.2	5.5
Flexion	16.7	15.3
Extension	14.4	18.3

The results show small differences or symmetry between right and left hands for most of the posture categories. Further, there were no major differences concerning experience level and job manipulation category (see Section 3.3). Wrist ulnar deviation and pinching were the predominant wrist activities for most of the observed jobs. Right and left hand radial deviation was used less than 10 percent of the time by more than 70 percent of the subject population. Eleven employees used left hand pressing for 30 to 50 percent of the cycle time; only four employees used right hand pressing in the same duration category. The converse was true for the pinching activity. Eleven subjects pinched with the right hand for more than 60 percent of the time compared to five subjects who pinched with the left hand. Generally, the left hand was used for course manipulation involving a pinch grip and pressing to push or produce tension on the fabric. Fine manipulation was accomplished with the right hand, usually with a pinch grip.

3.4.2 Neck and Back

Overall, 40 percent (12) of the thirty subjects stooped forward (i.e., torso flexion) at least 20 degrees during the machine cycle. Sixty percent of the subjects tilted their heads more than 20 degrees throughout most of the machine cycle. This pattern did not change when looking only at the twenty-five subjects working at seated jobs. Sustained hunched-over work postures in excess of 20 degrees have been cited as a factor associated with muscle fatigue, pain and discomfort (Greenberg and Chaffin, 1976; and Grandjean, 1988).

3.5 SEATED WORKSTATION CONSIDERATIONS

3.5.1 Workstation Design

Sixty percent of the seated workers indicated during the interview that they lean forward, usually to get closer to the work. This reported adaptation to visually demanding work is supported by the video analysis results (see Section 3.4.2). The preponderance of pain in the neck and upper back (Figures 1, 2, and 3) can be attributed, at least in part, to this hunched working posture. This hypothesis is supported by a comparison between seated and standing workstations (Figure 3). Workers in seated jobs reported substantially greater frequency of upper back pain (55%) and neck pain (54%) than did those in standing jobs who reported corresponding frequencies of 39% and 22% for the back and neck, respectively. Several workers stated that this posture is necessary to obtain maximum job production and wages in the piece-rate industry.

The tendency of operators to perform work in a bent or slumped posture indicated a potential conflict between workstation and operator dimension. Analysis indicated that the treadle typically is located too close to the proximal edge of the work surface (perhaps due to optimization for the 5th percentile or small operator). The conflict between leg room, comfortable leg posture for treadle operation, and the need for handling the piece at the point of operation (POO) results in one of two general postural adaptations. The most frequently observed was the case of nominal leg position (lower to upper leg angle roughly 110 degrees or greater) combined with 25-30 degrees of upper body deviation from the vertical. A second, rarely observed posture brought the operator closer to the POO at the expense of leg comfort (lower to upper leg angle 90 degrees or less). This second posture typically required foot extension (acute foot-lower leg angle) to maintain the machine in an idle mode and a greater degree of extension combined with twisting of the ankle to engage the treadle activated presser foot release.

Support for this observation came in two forms. In the operators measured, the average distance from the back of the chair (approximating proper normal back position) to the POO was only 3 cm less than the arm length of the 50th percentile operator. This indicated that dynamic activity at the POO would require a shortening of this distance (average reach required 84 cm, recommended reach 45 cm or less)(Kodak, 1983; Tichauer, 1978). The second analysis concerned treadle position. Average treadle position was roughly 15 cm from the proximal edge of the work surface.

A second factor limiting operator access to the workstation was the location of various obstructions under the work surface. These obstructions were typically drive motors, pneumatic equipment, power or pneumatic lines, and various machine guards. It is probable that these devices were located under the work surface to minimize interference with the work being performed on top of the surface, to create additional floor space, and even to improve equipment and personnel safety (relating to trip and fall hazards, burns, shock, etc.). However, the placement of these devices was not optimal for operator access in the majority of cases.

While typical minimum recommended leg/knee room averages around 46 cm (Diffrient, et. al., 1985; Kodak, 1983), the presence of these obstructions in some cases limited available space to less than 25 cm. Leg clearance also proved to be a problem in some cases where obstructions under the work surface reduced clearance room by 5-8 cm. This problem was somewhat insidious in that the clearance distance from the floor was still adequate in most cases, but with the placement of the foot on a treadle located around 8 cm off the floor, the potential for upper leg compression due to lack of clearance became evident.

The resultant postural adaptations that the obstructions and treadle placement necessitate contribute to fatigue. The most probable high impact areas would be the neck, upper back, shoulders, middle and lower back and arms. The greater distance from operator to POO also increases sight distance on a task which typically requires high acuity at the POO.

3.5.2 Chair Design

The chairs typically encountered in the sewing environment were generally too small in the seat pan, lacked any cushion for reducing compression and fatigue, lacked (though not in all cases) adjustable backrests, and were not properly adjusted in height. The chairs often had no provision for swiveling or other motion and no armrests for upper extremities support. In some cases, chair height was modified by the plant in conjunction with an increase in height in the workstation to accommodate the use of clamp trucks for garment bundle transport. These factors resulted in operator adaptations including the use of pillows or pads to improve comfort and seat support.

In contrast with recommended seat pan dimensions of 41 cm in length and 43 cm in width (Diffrient, et. al., 1985; Kodak, 1983) the average chair measured roughly 35 cm in length and 35 cm in width. In plants with chairs at normal heights, the height of the chair approximated the recommended height of around 40 cm off of the floor for the average female operator. However, the lack of adjustability would impact smaller and larger operators. The treadle height typically required a foot position at an additional 7-8 cm above the floor. At this height the larger operators' thighs would be largely unsupported and an uncomfortable acute torso to leg angle would be required to perform operations, exacerbating the conditions already noted under Section 3.5.1 (Workstation Design). At workstations adjusted for clamp trucks, seat height averaged 62 cm while treadle height averaged 24 cm. The stations adjusted for clamp trucks were not typically provided with a footrest for the operator to support the leg and reduce compression on the back of the thigh. For comparison, the 50th percentile female operator popliteal height was 41.7 cm.

Cushions were utilized by most operators (91 percent of the seated interviewees) with the possible benefits of improved height and increased pliancy and area of the load bearing surface (which would tend to reduce the effects of compression on both the buttocks and thighs as well as increase comfort). Some operators also used cushions on the chair back. The average cushion adjustment increased seat height by 3-6 cm when compressed.

3.5.3 Workstation Raw & Finished Material Access

Bundled materials were typically delivered on a clamp truck or horse-type cart. Location of the cart was adjustable by the operator in most cases. However, proximity to the operator's workspace was often limited by the amount of room required by the operator for processing the garment or piece and lack of physical space. This resulted in reaches to raw materials of roughly 48 cm on average with a discharge reach of 60 cm to finished goods. A recommended reach envelope for frequent lifting is 40 cm. Space problems frequently required that operators locate the truck or horse at an angle of 85 degrees or greater to the orientation of the torso. This required the operator to reach over and in some cases back at arm's length to obtain and discharge the materials. Operators were also observed twisting in the chair during lifts and attempts to move the cart or truck.

Note that operators using horses tended to pick up raw materials from one side of the body in a bunch of 4-8 pieces weighing 2-4 kg and discharge finished goods one piece at a time on the opposite side. Operators using clamp trucks handled single pieces (weighing an average of 0.5 kg) and acquired and disposed of them on the same side of the body.

3.5.4 Treadle Force

Treadle forces required to activate and sustain machine operation showed a great deal of variability. Only one plant's range of forces (though still highly variable) fell within the recommended ranges (Kodak, 1983; MIL-STD-1472C, 1981). The problem appears to be in maintenance. As the clutch device wears, the level of force required to activate the treadle changes. The result is a wide variation in forces required to operate between machines.

TABLE 6. COMPARISON OF MEASURED VERSUS RECOMMENDED FORCE RANGES FOR TREADLE ACTIVATION FOR ALL SITES

	Measured	Industrial (Kodak)	MIL-STD-1472C
Force range	5-98 N	15-90 N	45-90 N

3.6. ENVIRONMENTAL CONSIDERATIONS

3.6.1 Noise

Noise levels indicated the potential for exposure above U.S. OSHA regulations in some cases. Overall, the sites averaged roughly 82 dBA ambient with a mean of 83 dBA measured at the operators' ears. Dosimetry results identified serging as a consistent exposure area above the OSHA specified Action Level of 85 dBA for an eight hour shift and, in at least one case, above the permissible exposure limit of 90 dBA. The high noise levels in the serging areas are attributable to several factors:

1) The practice of grouping serging machines in a task cluster
2) The resultant maintained noise level due to several machines operating simultaneously during the majority of the shift so that the overall exposure rarely drops off
3) The combination of high frequency air noise and impact noise characteristic of serging machines

3.6.2 Illumination

Most sewing operations are visually demanding. Therefore, less than adequate lighting could cause workers to assume a hunched over posture to gain vision down into the work. The average general illuminance on the workstation (N=396) for all three locations was 78.4 footcandles (fc). Task illuminance, considered to be the combined illuminance of supplementary plus general lighting, was 168 fc. Whereas Plant A and B had similar values, they were substantially less than the Plant C facility averages. This appears to be due in part to the more effective use of fluorescent luminaires (i.e., lamps plus fixtures) at Plant C. In all three cases, however, most workstations provided less than 60 percent of the IESNA recommended value of 300 footcandles for performance of visual tasks of low contrast and very small size over a prolonged period. For working on white material with a high reflectance the recommended value is 200 fc. Most workstations provided less than 90 percent of this value. Sewing machine operators often do not use the available task lamps (i.e., supplementary lighting) or position them so they are less effective. Furthermore, in Plants A and B many fixtures were poorly maintained. Overall, 36 percent of the employees interviewed considered lighting to be a problem. Age and experience might be factors as 53 percent of workers in the 36 to 45 year age category and 53 percent of workers with 5 to 10 years experience reported lighting as a problem at least sometimes (i.e., at least a 2 rating on a 1 to 4 scale).

3.6.3 Temperature

Overall, the temperature levels in the sewing work environment reflected a nominal level of thermal comfort with with little fluctuation in temperature. Average temperatures ranged between 73-74 degrees F with an average WBGT ranging 65.7-67.6 degrees F. The mean dry bulb temperature varied less than 1 degree and WBGT index varied by less 2 degrees between plants. Distributions within plants were also fairly narrow with low standard deviation (e.g., 0.2 typical). These readings were obtained in plants which were climate controlled with air conditioning systems during the summer months. With the exception of non-air conditioned spaces and some types of pressing operations, thermal levels measured fell within the comfort range (roughly 68-78 degrees F). Even so, 87 percent of the interview population reported a problem with temperature at least some of the time.

3.7 TRAINING CONSIDERATIONS

Training of workers in the apparel manufacturing industry is an important consideration. Many of the jobs require the operators to learn complex psychomotor skills that can take many months to fully develop. In some jobs, as much as four months practice are needed to obtain the minimal skill level required to meet the standard production rates. Yet, apparel manufacturing in the Southeast is a high-turnover industry due, in great part, to the demand for inexpensive labor by other industries. Expensive training investments can be lost when new workers leave before or soon after their rates approach profitability.

Increases in production and productivity could be achieved if improved training methods reduced the time required for the development of the required sewing skills. Yet, at the sites studied in this phase, training was inconsistent and did not use methods found to be effective in other industries.

Initial training of sewing operators was performed as on-the-job training in all three of the plants we examined. One plant had a specialized training department responsible for initial and continuing training; the other two plants provided training by the floor supervisor. Training periods varied from a few days to as much as four months. None of the plants provided formal specialized training for their supervisors and trainers in effective methods for providing training and performance feedback to new workers or those transferring to a new job.

The 121 female sewing operators interviewed during the site visits were questioned about the training they received at the sites under study. Most reported that training consisted of a brief demonstration of the proper way to perform their assigned job with occasional follow-up suggestions at later times. Only 17% reported that they were shown or provided with any kind of charts, pictures, or written descriptions of how to perform their jobs.

The use of videotapes is gaining acceptance in many industries as a way to train psychomotor skills. Two of the three sites that were studied are making some use of videotapes but tapes are typically being made for engineering purposes rather than training.

Videotapes can be used to demonstrate exemplary performance. Star workers can be taped so that their work procedures and methods may be shown to new operators in that position to show how the job should be done and to prove that it is possible to make the required rates. In addition, tapes can be made of the person being trained in order to show deviations from the desired work methods. Videotapes provide the flexibility to allow slow-motion studies of methods and they can be replayed, in full or in part, as often as desired.

Of the operators interviewed, 13% reported that some use of videotape had been made during some portion of their training. Of the 16 operators who reported that videotape had been used, 31% reported that the tapes were used during their initial job training period while 69% reported that they were used during a change of jobs or to provide suggestions for improved work methods on their original job. Fifty-six percent of these workers reported that the slow motion capability was used to enable them to better see the sewing techniques being demonstrated. Sixty-three percent reported that they were allowed to study the tape for as long as they wanted while 37% would have liked more viewing time. Eighty-one percent reported that someone (a supervisor or engineer) was present to explain what they should learn from the tape while it was being shown.

Because of the hunched posture adopted by most of the operators, the interviewees were asked whether they had ever been instructed in the importance of correct posture while they are working. Only eight percent reported receiving such instruction. At one site, management stated that posture instruction is mandatory for all operators but, at this site, only four percent recalled receiving such instruction. Obviously, if such instruction really is being presented, it is not having a major impact on the workforce.

Numerous jobs require the handling, lifting or moving of relatively heavy loads such as bundles of trousers. Yet, only ten percent of sewing operators reported that they had received training in the proper way to lift heavy articles. Seventeen percent of the operators reported that they had received instruction in other safety-related aspects of their jobs.

There was evidence, however, that improvements in employee training are being made, especially in the training of newly hired workers. Table 7 shows the percentage of workers at each of three experience levels who reported receiving training using visual aids and video tape, on posture, on lifting, and on other safety issues.

TABLE 7. PERCENTAGE OF OPERATORS REPORTING EACH KIND OF TRAINING

EXPERIENCE LEVEL (YEARS)	VISUAL AIDS	VIDEO TAPE	POSTURE TRAINING	LIFTING TRAINING	SAFETY TRAINING
LESS THAN 3	30%	10%	17%	13%	30%
3 - 10	15%	18%	7%	14%	14%
MORE THAN 10	12%	13%	5%	6%	11%

Based on these data, there appears to be a trend toward more complete training among the younger workers. The exception seems to be in the use of videotape in training. Recall, however, that operators reported only infrequent use of videotapes during their initial training. These data would suggest that the recent use of videotapes has concentrated largely on the more experienced workers rather than as a tool for initial training.

Performance feedback is an important element of psychomotor training. Because of the piece-rate nature of the industry, it is relatively simple to assign performance measures based on the number of pieces produced and the number rejected by inspectors. In one plant, a daily record of pieces produced is plotted against an ideal learning curve and posted above the workspace of each trainee. More direct and immediate means of feedback and performance remediation might be more effective.

In one plant, a computer controlled conveyor line provides a capability to display instantaneous readings of the current rate and earnings achieved by the operator on a screen at each workstation. Operators report that this capability is seldom used because it requires several keystrokes to obtain this display and the data are in a format that is not easily interpreted.

Recommendations for the improvement of training are included in Section 4.4 (Conclusions and Recommendations) of this report.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 ANTHROPOMETRY

When utilizing anthropometric data as an aid to workstation design, an appreciation of the following considerations can prove useful:

In examining the evidence, it is apparent that a design for an average person will not accommodate the significantly larger or smaller individual. To correct for this, designers usually will attempt to address the 90 percent of the population between the 5th and 95th percentiles. However, individuals will vary in their percentile score on each particular dimension. A person of 95th percentile height may have a 85th percentile arm length, etc. Additionally, every sub-population (e.g., all female operators in a plant) may vary from the larger population (e.g., HEW civilian females) as illustrated in Tables 1, 2, and 3. Considering these factors as well as the dynamic nature of the work performed at a sewing workstation, it becomes apparent that workstation design dimensions must incorporate adjustability to accommodate as much of the workforce as possible.

The data from this study may be used as a reference for designers attempting to develop equipment for the apparel manufacturing environment. The statistical significance of departures from the larger populations has not been assessed. However, the variations between the study data and existing sources of anthropometric design data indicate the need for proceeding with caution when utilizing these general design data sources.

4.2 WORKSTATION DESIGN

Among parts and assembly sewing operators, complaints of musculoskeletal discomfort focused on the upper extremities and torso. Video analysis of the target jobs revealed the presence of biomechanical or postural stressors that might account for this reported discomfort. The one common problem that clearly needs to be addressed is the lack of adequate chair and workstation adjustability.

All target jobs were hand intensive and the use of ulnar deviation, grasping with a pinch grip, and flat pressing was commonplace. This finding is important since forceful exertion (e.g., pinching), repetition, and non-neutral wrist postures (e.g., ulnar and radial deviation and flexion and extension) have been implicated as risk factors of cumulative trauma disorders. However, there was insufficient epidemiological data to support any relationship between posture, discomfort, and disease. With a large number of interviewees reporting night numbness of the hands, it is apparent that further research is needed to accurately determine the prevalence of CTDs in trouser manufacturing.

To eliminate the use of hand motions altogether will require automation. To reduce the amount of activity will require both workstation modifications and a careful examination of the piece rate system of payment that might encourage working at a fast pace. Wick and Drury (1986) have reported success in reducing the frequency of severe torso flexion, hand motion and ulnar deviation by modifying the workstation and providing adjustable chairs. Ostensibly, some of the high risk hand activity is nonessential and could be reduced through structured training in the importance of motion economy and biomechanics. But it is generally agreed that the training effect is at best temporary and will require further investigation.

It is well established that frequent and sustained forward flexion of the torso creates stress on the neck, back, and shoulders. The two factors identified that alone or together can cause the worker to assume this posture include poor lighting and a point of operation outside the normal viewing zone and reach envelope. The point of operation incompatibility is created by a rigid workstation and chair and/or the lack of adequate leg and table space. In Phase II we will measure the impact of using an easily adjustable, upholstered chair in combination with adequate lighting and posture training on back and neck posture and on emloyee comfort.

Frequent lateral reaches to acquire and dispose of fabric bundles can add to the loading of shoulder muscles, promoting muscle fatigue. This reaching activity in conjunction with chairs that lack a swivel capability can cause the employee to twist his/her upper torso, creating large stresses on the back. The use of swivel capable chairs, horses, clamp trucks, and other between station delivery systems should allow workers to transfer the garment or raw material without bending, twisting, or excessive reaching at or above shoulder height. Spring-loaded or self-leveling carts might prove useful. The design of the clamp trucks that require workstation height adjustments for their use needs to be re-evaluated by the manufacturer. The industry should seek a design that would be compatible with existing workstations and would allow trouser transfer without the garment legs dragging on the floor.

To promote comfort and work tolerance at standing workplaces, antistress mats could be used for more even weight distribution on the feet. Although sit-stand is preferred, it is not recommended for workstations that require a high degree of movement between task locations (e.g., zipper stop). PW back pockets was seen as both sit or stand. As with most work, the point of operation should be within two inches of elbow height (which can be estimated by taking sixty-three percent of stature).

Hand and power tools were rarely mentioned by interviewees as causing discomfort. This might be due in part to the absences of specific interview questions concerning their use. In any event, some employees were seen wearing band-aids which is indirect evidence that the frequent use of clippers and scissors might be a stressor. Scissors that are spring-loaded to assist the scissors opening process are commercially available, but their impact on comfort and performance is inconclusive (Tannen, Stetson, et. al., 1986). More consideration needs to be given to designing handles to allow workers to maintain a straight wrist while pressing, cutting, and trimming. Irons, trimmers, and cutters also need to be counterbalanced so the operator does not need to support the weight of the device. Vibration may be a potential problem with poorly maintained trimmers

To keep the treadle activating force to a minimum, all machine treadles should be checked on a regular basis. Excessive force could result in leg and foot muscle fatigue.

4.3 ENVIRONMENTAL FACTORS

Inadequate illuminance can effect work performance and cause the operator to assume stressful postures to reduce the viewing distance from the work. Training in the use of available task lighting is needed and should focus on the need for adequate lighting and on proper lamp positioning. Maintenance of existing fixtures is also an important issue. When lamps begin to fail, they should be replaced immediately. For more effective overhead or general lighting, individual companies should consult with illumination engineers or consultants.

While the temperature ranges measured showed a level of temperature and humidity nominally within the comfort range, temperature ranked highest on the environmental problems section of the interview. However, perception of thermal comfort has a high degree of variance between individuals. Influences on perception of temperature may include the time of day, diet, hormonal imbalances, season, type of clothing, etc. (Fanger, 1970).

With ambient noise levels averaging above 80 dBA, trouser manufacturing environments may need sound level assessment. This will of course depend on the nature and density of the noise source(s). Futher, it is important that equipment manufacturers apply the available and emerging noise suppression and abatement technologies in the equipment they design, manufacture, and distribute.

4.4 TRAINING

More effective training could increase productivity and improve safety. We would make recommendations in three basic areas: (1) training for the training staff, (2) increased use of audiovisual aids, and (3) performance feedback during training.

One of the most common mistakes made by organizations is the assumption that expert knowledge about a job is enough to make a person an effective teacher. In order to provide effective instruction, the trainer also needs to know something about the principles of learning and how to use them to best advantage. We would recommend that trainers, or supervisors who are called on to provide training, should be given at least a brief seminar on the use of learning principles in this specialized environment.

Audiovisual aids, including paper products such as job descriptions and diagrams and more advanced aids such as videotapes can produce a significant improvement in training effectiveness. Diagrams of correct techniques for operating equipment, posture, hand positions, and proper safety practices are learned more quickly and are remembered longer than simple verbal instructions, especially by the novice worker. Videotapes can be an even more effective training tool if they are effectively used to demonstrate ideal methods and performance. They are especially effective if a trainer is available to guide the training process, if features such as slow motion and multiple playbacks are used, and if the trainee has an opportunity to practice the skills during or immediately after presentation of the videotape training session.

It is important to provide immediate feedback to the trainee during practice of the job. Such feedback should have both performance and diagnostic components (e.g., your average cycle time was 47 seconds and you are making three significant extra hand motions that are slowing your time.) Because of the piece-rate nature of the industry, performance feedback is available on a daily basis. It could be available more often if the operator wanted to take the time to track production across smaller units of time, but this would be inconvenient and time consuming. As previously mentioned, computer controlled conveyor systems allow the achieved rate to be calculated and displayed, but this process is somewhat cumbersome and is seldom used. None of these approaches allows the kind of diagnostic feedback that is important to training in effective work methods. At a minimum, strict supervision by the trainer is important during the early periods of training and practice to ensure that proper methods are being learned. Videotaping of the trainee at selected times during the training period and careful review of the tapes with the trainee (using features such as slow motion) would provide better diagnostic feedback as well as allowing calculation of production speeds.

5.0 FUTURE CONSIDERATIONS

Some preliminary observations were made on an advanced technology computerized conveyor system seen at one plant location. The interview data showed that workers using this system (N=12) expressed a higher level of hand and leg discomfort than their counterparts that did not use the system. These preliminary results and observations will be carefully examined in Phase III. Initial observations are as follows:

1) The conveyor system may contribute to the ambient noise level.

2) The horizontal reach component was less at the advanced technology workstations. However, it might add a vertical component, which increases pronation in the acquisition of materials.

3) This conveyor system eliminates most cart or truck handling activities and allows the garment to approach the operator. Fewer pieces are handled at one time.

4) Flexible delivery (as opposed to standard rail delivery) may reduce some of the reach and posture problems noted in (2). The flexible system allows individual adjustment of delivery height and provides additional tolerance for pulling the garment to the workstation.

APPENDIX A

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APPENDIX B

INTERVIEW FORM

Date ______________________
Plant ______________________
Interviewer ________________

General
The following information will be used for describing the participants in terms of age, job, sex, and experience, and also in summarizing the results by those categories.

Job Title ________________________________
Job is performed while: seated standing both. Age ___ Sex M F
How long employed at this plant ______________/on this job _____
Extent of previous employment in similar job (approx. years) _____

Major hobbies and sports activities (estimate average #hrs/week):

____

____

____

Medical Background
During the past twelve months, have you been treated by a doctor for any problem related to the muscles, tendons, or joints of your body? Examples of these problems are back strain, arthritis, tendonitis, herniated disc, and carpal tunnel syndrome. Yes No

If yes -- indicate diagnosis

____

____

Since you began working at this plant, have you ever worn a brace or support of any kind due to an injury or soreness? Yes No

(If yes -- indicate what and why) ____________________

____

Physical Discomfort

The following questions are about physical discomforts you may experience while working, or that you believe are work-related. Use the following scale to indicate how often you have experienced pain or stiffness in each body part within the past 6 months (or since starting to work here, if less than 6 months). (circle one)

	Never	Sometimes	Frequently	Constantly
Right hand/wrist	1	2	3	4
Left hand/wrist	1	2	3	4
Right arm (incl. elbow)	1	2	3	4
Left arm	1	2	3	4
Right shoulder	1	2	3	4
Left shoulder	1	2	3	4
Right foot/ankle	1	2	3	4
Left foot/ankle	1	2	3	4
Right knee	1	2	3	4
Left knee	1	2	3	4
Right leg	1	2	3	4
Left leg	1	2	3	4
Upper back	1	2	3	4
Middle back	1	2	3	4
Lower back	1	2	3	4
Neck	1	2	3	4

Do you ever have numbness in any of your joints at night? Yes No
(If Yes, elaborate below)

____

Do you ever have a problem with your feet or legs going to sleep while you are working? Yes No

List other physical discomforts you have experienced within the past 6 months that you believe are work related (for example, eyestrain, leg cramps, etc.):

____

Environmental Problems

The following questions are about problems that you may experience in your work environment. Use the same scale to indicate how often each condition creates problems in your job.

	Never	Sometimes	Frequently	Constantly
Temperature (hot/cold)	1	2	3	4
Drafts	1	2	3	4
Odors/fumes	1	2	3	4
Equipment noises	1	2	3	4

Other distracting noise	1	2	3	4
Amount of light	1	2	3	4
Glare from lights/windows	1	2	3	4

List any other environmental problem: ______________________

Chair Design and Use

The following questions are about the chair you use while working. Answer Yes or No to each question. Skip these questions if your job is performed entirely while standing.

Does your chair have the following features:

adjustable seat height	Yes No
adjustable backrest	Yes No
swivel side to side	Yes No
tilt front to back	Yes No
armrests	Yes No
wheels or rollers	Yes No

(If seat height or backrest are adjustable, answer the following.)

Has anyone shown you how to adjust your chair? Yes No

Did anyone adjust the chair so it would be right for you? Yes No

Can you adjust the chair yourself? Yes No

Have you adjusted the height of your chair by putting it on planks, blocks, or similar items? Yes No

Have you used cushions in your chair to:

Raise your seating height?	Yes No
Be more comfortable?	Yes No

Do you use a footrest? Yes No

Do you have enough legroom under your work table so that your knees and legs are comfortable? Yes No

Workstation Design and Use

The following questions are about your workstation. Answer Yes or No to each question.

Does your job require you to:

- stretch either arm fully (or almost so) to reach things? Yes No
- bend, lean, or stoop to reach things? Yes No
- raise either arm above your shoulder? Yes No
- lifting a bundle (or other heavy item) with your arms? Yes No
- carry heavy loads from one place to another? Yes No
- push or pull a cart or horse? Yes No

Do you have enough space for:

- the stacks of pieces you work on? Yes No
- other work items (supplies, clippers or scissors, etc) Yes No
- personal items you have at work (purse, coffee cup, etc) Yes No

Do you ever have a problem with:

- work table height (too high or too low)? Yes No

- height/placement of your pedal, treadle, or knee switch? Yes No
- having to lean forward to see what you're working on? Yes No

List any other workstation problem: ______________________________

Training

The following questions are about training you may have received at this plant. Remember that the questions are about training at this plant -- not other places you may have worked.

When you first started to work here, how long was your training period?

____

Have you received additional job training (such as for a different job) since then? (Indicate what type and how long)

____

____

In any of your job training at this plant, have you been given charts, work diagrams, or other written job descriptions to study and/or keep for yourself? Yes No (If yes -- indicate what)

____

Have you ever been shown a videotape of someone performing your job or a very similar job? Yes No

If yes --

Was this done when you first trained for the job? Yes No

Did you see it in slow motion? Yes No

Were you allowed to study the tape as long as you wanted to? Yes No

Did someone point out the major things you should be watching on the tape? Yes No

Have you ever been trained or instructed about the importance of correct posture in making you comfortable while working? Yes No

Have you ever been trained or instructed about the way to lift bundles or other heavy items? Yes No

Have you ever received safety training to show you how to operate your machine to reduce risk of accidents and injuries? Yes No

List any other special training you have received at this plant:

____

____

Work Schedule
These last questions are about how well your work schedule meets your needs. Answer Yes or No to say whether you think each thing would be better for you.

Earlier start time and quit time	Yes No
Later start time and quit time	Yes No
Longer lunch break	Yes No
Longer coffee breaks (indicate NA if not applicable)	Yes No
Flexible work hours (you get to choose what 8 hours you work between, say, 7 am and 7 pm)	Yes No

General Comments

Is there any part of your job that you think is a lot harder than other parts? Explain.

____

____

____

____

____

Now tell us more about any problems you mentioned in the earlier questions, and tell us anything else you believe would help make your job better for you.

____

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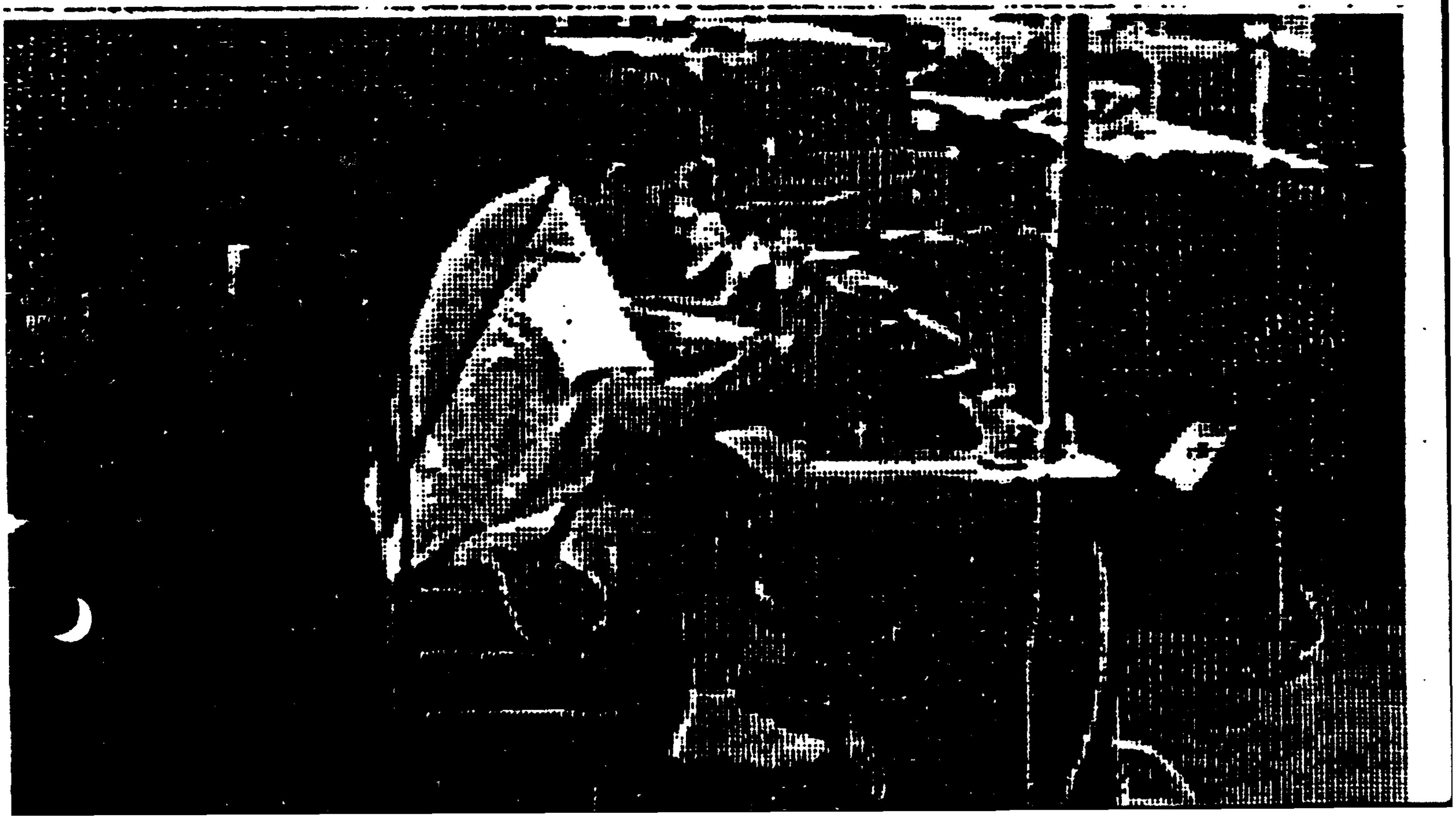
APPENDIX C

SEWING OPERATOR EXAMPLES



APPENDIX D

PHASE II: THE CHAIR AS AN ERGONOMIC INTERVENTION IN CONVENTIONAL TROUSER MANUFACTURING

DESIGN AND DEVELOPMENT OF A SELF STUDY COURSE FOR APPAREL SUPERVISORS IN THE PRACTICAL APPLICATION OF OF ERGONOMICS PRINCIPLES

PHASE 2 REPORT:

THE CHAIR AS AN ERGONOMIC INTERVENTION IN CONVENTIONAL TROUSER MANUFACTURING

Research Sponsored by:

U.S. DEFENSE LOGISTICS AGENCY

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TABLE OF CONTENTS

TABLES

FIGURES

SUMMARY

Sewing operators in apparel manufacturing plants typically use hard, straight-backed metal or wooden chairs. Often, the seat pan height and backrest position are not adjustable. While the operators typically customize these chairs with cushions or foam padding, the chairs still do not promote musculoskeletal comfort or a lordotic seated posture. Consequently, these operators frequently experience discomfort in the back and neck.

The effectiveness of an ergonomically designed chair for reducing or eliminating postural and musculoskeletal discomfort for operators in an apparel manufacturing plant was investigated. The padded chair provided easy adjustment of seat height, backrest position, and seat pan tilt. The front of the seat pan was formed in a "waterfall" shape to prevent the blockage of circulation to the lower extremities that is often experienced with flat seat pans with sharper corners. The chair was designed to provide backrest support through a range of seated positions.

During preliminary surveys, 12 female sewing operators rated their level of discomfort in 15 specific body areas at approximately two-hour intervals during the working day. In addition, videotapes were made for later motion and posture measurements. The subjects were then divided into two groups of six subjects each for the remainder of the study. Control group subjects received training and recommendations on chair and workstation adjustments and working posture. Experimental group subjects received training and recommendations on workstation adjustments and working posture and they received the ergonomically designed chairs for their use during the study period. After five weeks, all subjects were interviewed and the semi-hourly comfort surveys and videotaping were repeated.

Two weeks into the study, one experimental group operator was unable to adapt to the ergonomic chair and asked to withdraw from the study. She reported increased levels of leg and back pain, which she attributed to the swivel motion of the chair. The remaining five operators using this chair adapted well to the change.

While all subjects who completed the study showed improved musculoskeletal comfort, not only in the back but also in the upper and lower extremities, the experimental group showed a significantly greater overall improvement than the control group. During the preliminary surveys, all subjects reported increasing discomfort throughout the work day. During the follow-up surveys, the control group again reported increasing discomfort through the day while the experimental group maintained a relatively constant comfort level. In spite of the increased comfort shown by both groups, there were no changes in production efficiency that could be attributed to the chairs or training.

BACKGROUND AND OBJECTIVES

In order for the United States apparel industry to maintain and improve its competitiveness in the world marketplace, it must adopt emerging manufacturing technologies and achieve the maximum benefit from them. During the transition to a high technology manufacturing environment, jobs and workplaces should be designed to promote employee productivity, comfort, and safety.

Ergonomics (the study of the physical and mental characteristics and limitations of workers and the design of jobs and equipment to take these factors into account) has been effectively applied in many working environments. These include transportation, health care, mining, textile manufacturing, and a host of others. For various reasons, the practice of ergonomics or, alternatively, human factors engineering, has not yet been extensively applied in the apparel manufacturing environment.

Under a two-year program, Georgia Tech is exploring human factors problems in trouser manufacturing facilities in the Southeastern United States and identifying and testing cost-effective interventions for the uncovered problems. Lessons learned from this initial exploration will be used to predict and address related human factors issues in the apparel factory of the future as represented by the Apparel Manufacturing Technology Center. The principal objective of this program is to develop a comprehensive set of specially tailored ergonomics training and reference materials that will help apparel manufacturing supervisors and management:

(1) Identify workplace tools, layouts, and procedures that are incompatible with the characteristics and limitations of the workforce.

(2) Identify options for addressing the identified problems.

(3) Choose and implement ergonomically appropriate solutions.

The materials will specifically address ergonomic aspects of conventional and advanced manufacturing environments in which trousers are produced.

The objective of the initial phase of the project was to collect background data on existing conventional manufacturing workplaces and worker populations. The Phase 1 Report contains a detailed profile of ergonomic conditions in conventional trouser manufacturing. The second phase, on which this report is based, focused on the impact of an ergonomic intervention (an adjustable, ergonomically-designed chair for the sewing environment) on operator comfort, posture, and production efficiency in one facility. During the third phase, researchers will investigate ergonomic concerns in advanced technology apparel manufacturing. In the fourth and final phase, the information contributed from each of the previous phases will be combined into the self-study ergonomics course.

1. INTRODUCTION

Trouser manufacturing, whether in a conventional or high-technology workplace, is a highly labor-intensive process with 20 or more distinct steps. Each of these steps involves the operation of one or more kinds of power equipment such as specialized cutting and sewing machines. The steps require significant amounts of manual manipulation of fabric bundles, individual pieces, and unfinished garments as they are transported, inserted into, and guided through the machines. Tasks are highly repetitive, visually demanding and frequently performed while seated.

Seated operators comprise roughly 75% of all operators in the contemporary work environment (Grandjean, 1988). Advantages which have contributed to extent of seated work include reduction of physiological energy expenditure, relief of lower extremity loading, improved lower extremity circulation and potential reduction of related fatigue. However, these are countered by several disadvantages.

When standing, the vertebrae in the lumbar region (low back) adopt a forward curved or lordotic posture. This lordosis allows the spine to better distribute the loads imposed by the torso and upper extremities and facilitates a mechanical advantage for the extensor muscles in the low back. In a sitting posture the pelvis and the attached sacrum rotate backwards flattening the lordotic curvature and even creating backward curvature or kyphosis in the unsupported lumbar region (See Figure 1). This change in the curvature of the lumbar region increases pressure in the intervertebral discs and stresses the discs, low back muscles, ligaments and spinal nerves (Andersson, 1986; Nachemson and Morris, 1964; Yu and Keyserling, 1989). Kyphosis may become more pronounced as extensor muscles become fatigued and transfer additional load to the ligaments. Long term effects of such postures may include disc and nerve disorders.

A second consideration is that in a seated position the majority of the upper body weight is carried by two small, bony prominences on the underside of the pelvis known as the ischial tuberosities. These structures and the tissues beneath them are particularly adapted for weight-bearing (Floyd and Roberts, 1958). However, as an individual bends forward, the weight begins to shift to the soft tissue of the thighs which is relatively unsuited for load support. The resulting compression of nerves and blood vessels can cut off circulation and create numbness, aching, and loss of sensation in the thighs.

The effects of seated posture on the spine can be reduced with the use of a backrest. Upper body weight can be transferred to the backrest relieving discs, ligaments, and skeletal muscles of at least a portion of their load. This effect, as measured by decreasing disc pressure, increases as the angle of the backrest to the seat pan increases or as the size of the lumbar support increases (Andersson, 1986). The backrest also promotes lordosis.

FIGURE 1. EFFECTS OF SITTING ON SPINAL CURVATURE.

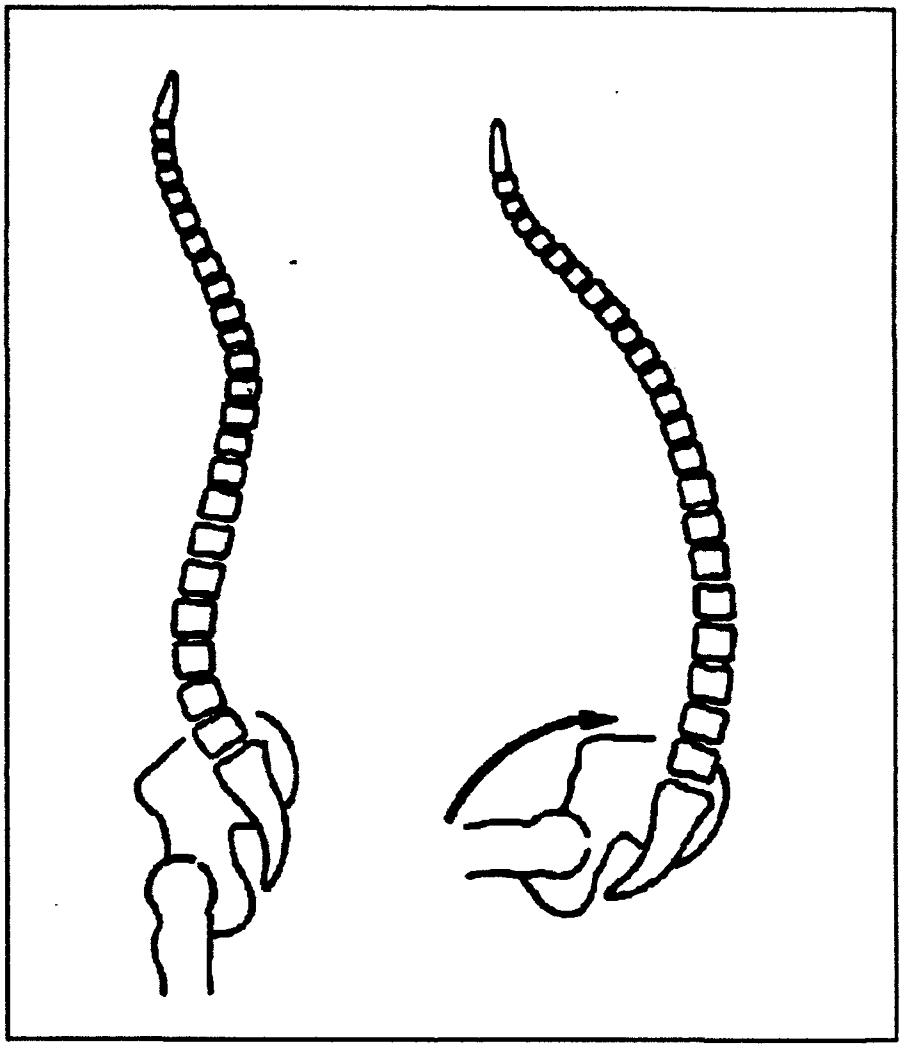


Illustration from Grandjean, 1988.

Figure 1- When standing (left), the lumbar spine (low back) assumes a lordotic or forward curved posture. When seated (right), the pelvis is rotated backwards forcing the lumbar spine to flatten (loss of lordosis) or become backward curved (kyphotic).

To further relieve spinal loading, improve lordosis, and relieve ischemic compression in the thighs, several researchers (examples: Mandal, 1976; Bendix, 1984; Congleton, Ayoub, and Smith, 1985) have evaluated chairs with forward sloping seat pans. The forward tilt of the seat pan allows the pelvis to rotate back towards the normal standing position distributing the load more evenly between the spine and skeletal components of the legs and creating a larger, trunk/thigh angle.

In Phase 1 of the current project (Ortiz, Kelly, Courtney, and Folds, 1989; Kelly, Ortiz, Folds, and Courtney, 1990), analysis of data from interviews, videotaping, and workstation measurement consistently identified seated tasks as problem areas. Of the 121 female operators interviewed, the incidence of discomfort reported for seated operators was markedly greater than that for their standing counterparts. Significant increases in discomfort incidence were noted for seated operators in the neck, shoulder, upper back, mid back and low back regions. Motion and dimension analysis indicated that poor seating in combination with operator/workstation dimensional conflicts promoted slumped or hunched postures in task performance.

The typical sewing chair studied in Phase 1 had a hard metal or wood seat pan, and the majority lacked adjustability in any dimension. The best of the chairs evaluated allowed incremental adjustment in height and some adjustment in backrest height and proximity. However, most of these adjustments could only be accomplished with the use of tools. Therefore, even these chairs could only be classified as marginally adjustable in the time intensive sewing environment.

Ninety-one percent of seated operators interviewed in Phase 1 attempted to compensate for chair deficiencies by adding cushions, pads, or pillows to the seat pan, the backrest, or both. Cushions were used to increase height, improve backrest comfort and proximity, and alleviate discomfort created by the compression of hard-surfaced, relatively sharp-edged seat pans. These operator adaptations further illustrated the problems with task seating in the contemporary apparel environment.

The extent of poor quality seating led to the selection of the chair as the target ergonomic intervention for Phase 2. The goal of the study was to evaluate the impact of a commercially available, ergonomically designed, adjustable chair on operator efficiency, posture, and comfort. Special emphasis was placed on experimental controls to reduce Hawthorne effects (Snow, 1927; Roethlisberger and Dickson, 1939) due to differences in subject treatment. All subjects whether in the experimental or control condition received similar measurement, training, and assistance. It was hypothesized that the ergonomically designed chair when combined with posture and chair adjustment training and assistance would have a significantly greater impact on operator parameters than training and assistance alone.

2. METHOD

SUBJECTS

Subjects were 12 sewing operators at a medium-sized apparel manufacturing plant in the Southeast. All subjects were female (as is typical of the population of sewing operators.) Four operators were recruited from the sideseaming position, four from the serging position, and four from the pocket face-and-close position. Subjects were paid for their participation.

APPARATUS

The chair selected as the experimental or test chair for the study was a commercially available model manufactured in the United States. The design reflected basic ergonomic concepts of adjustability, compression avoidance, and low back support and was based in part on results from studies performed for Ford Motor Company (Yu *et al.*, 1989). The chair was highly adjustable allowing effective operator control of seat height, seat pan tilt, backrest angle, backrest height, and backrest proximity from a seated position. The chair was adequately padded, and the front of the seat pan was formed into a "waterfall" curve to reduce the impact of the chair shape on lower extremity circulation. The chair swiveled through 360° to facilitate ingress and egress.

The control or conventional chair was typical of the better chairs examined in the Phase 1 study. It was not upholstered and did not swivel. Seat height, backrest height, and backrest proximity were adjustable with some effort, but tools were required. Reflecting the findings of Phase 1, subject operators had modified the chairs in all cases by adding cushions or pillows to either the seat, the backrest or both.

See Table 1 and Table 2 for a comparison of the chairs. See Appendix B for a detailed description of each chair.

EXPERIMENTAL DESIGN

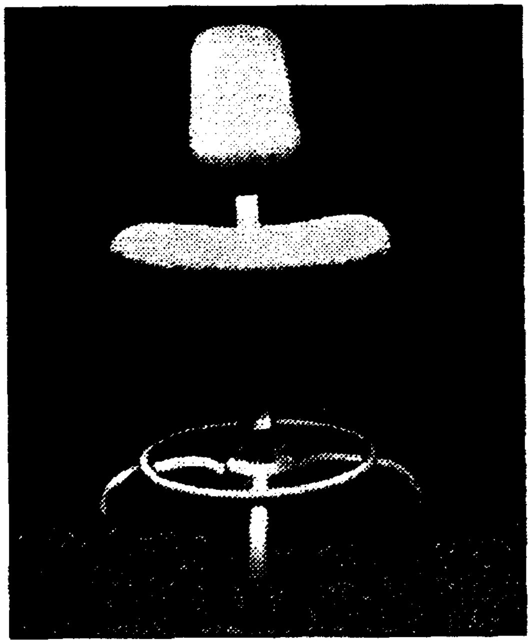
A between and within subjects design was used for the experiment. The four subjects in each of the three selected jobs were randomly assigned into experimental and control groups. Because of the strong effect of age on reported comfort found during Phase 1 research, an effort was made to match the experimental and control groups according to age.

Subjects in the experimental group underwent initial measurement in their own workstation chairs but were then transferred into the test workstation chairs for the duration of the study. Subjects in the control group were subjected to the same measurements as those in the experimental group, but used their own chairs (conventional) throughout the study.

TABLE 1.- TEST CHAIR/CONVENTIONAL CHAIR ATTRIBUTE COMPARISON

ATTRIBUTE	TEST CHAIR	CONVENTIONAL CHAIR
Height	42.0 - 53.0 cm	45.0 - 64.7 cm, fixed
Support System	Pneumatic cylinder	Fixed hardware
Pan Size	39.0 x 41.4 cm	38.3 x 37.0 cm
Pan Shape	Complex- concave/convex	Flat- slightly convex
Tilt	-4° - 7°	N/A
Padding	4.5 cm, average	None
Swivel	360°	None
Backrest Height[a]	8.5 - 21.8 cm	23.6 - 28.1 cm
Backrest Size[b]	30.5 x 18.5 x 21.0 cm	15.0 x 30.3 x 28.3 cm
Backrest Angle	80° - 106°	90°
Backrest Proximity[c]	1.0 - 15.0 cm	0 - 8.0 cm
Backrest Flexion	20°	N/A
Backrest Padding	3.8 cm thoracic 6.5 cm lumbar	None

a- Measured from top of seat.
b- Height x Top Width x Bottom Width.
c- Measured in from rear edge of seat pan.



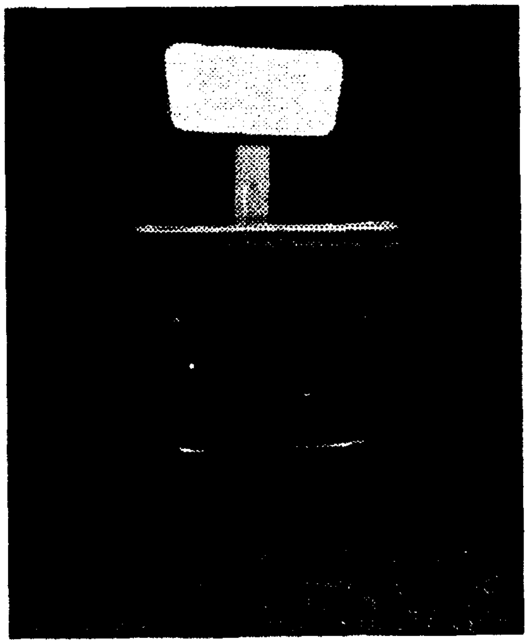
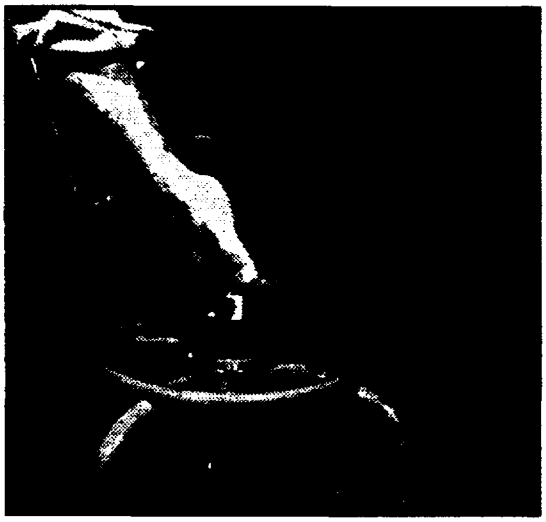
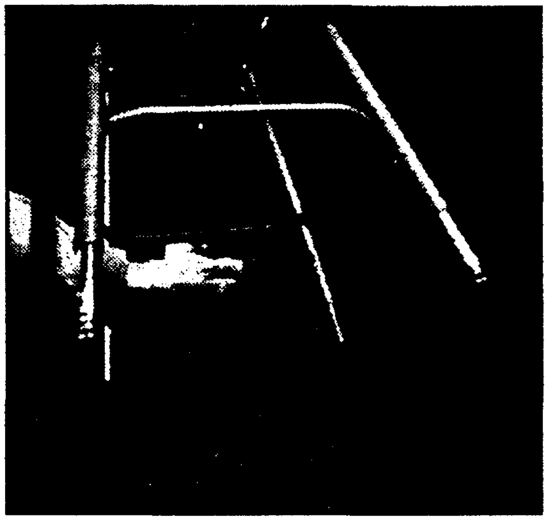


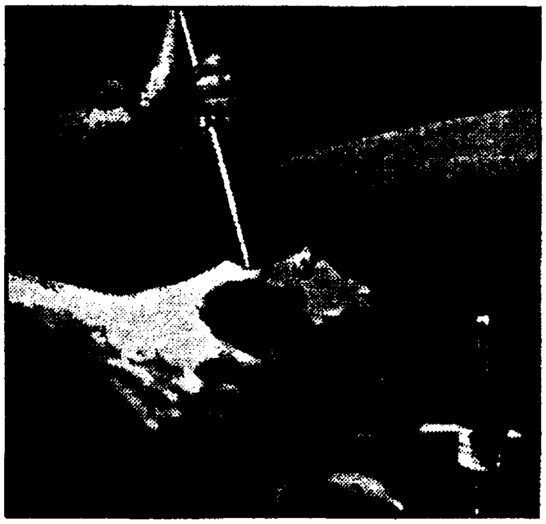
TABLE 2.- TEST CHAIR/CONVENTIONAL CHAIR ADJUSTMENT COMPARISON

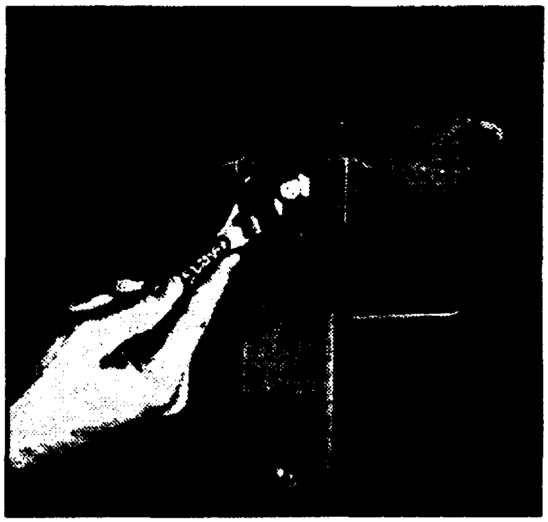
ADJUSTMENT	TEST CHAIR	CONVENTIONAL CHAIR
Height	Pull up on hand lever. Continuous. Y[d]	Unscrew and replace 4 screws. Tools: screwdriver, pliers 2.4 cm increments. N[d]
Backrest Angle/ Seat Pan Tilt	Pull up on hand lever. Continuous. Y[d]	Not adjustable.
Backrest Proximity	Pull up on hand lever. Continuous. Y[d]	Loosen and tighten wing nut. Continuous. N[d]
Backrest Height	Loosen and tighten knob. Y[d]	Loosen and tighten hex nut. Tools: wrench. Continuous. N[d]

d- Indicates whether adjustment may be accomplished from seated position (Y) or not (N).









Three types of measures were taken: body part map comfort data, video registration data, and production efficiency data. Comfort data and video registration posture data were collected twice, during week 3 and during week 8. Production data were obtained for two representative weeks before the research started, for the five weeks of the study, and for two weeks after the final comfort and video data were collected. Except for the data collections during weeks 3 and 8, the experimenters did not visit the research site.

Comfort Data

Comfort data were collected using a modified version of the body part map survey (See Figure 2) developed by Corlett and Bishop (1976). Subjects were asked to rate comfort on a 5 part, anchored scale with 0 being comfortable and 4 being very painful (Lee, Waikar, Aghazadeh, and Tandon, 1986). Subjects rated comfort at two hour intervals throughout a typical work day. Table 3 presents the design used for the comfort data collected on January 17 and again on February 22, 1990.

TABLE 3. EXPERIMENTAL DESIGN FOR COMFORT DATA

JOBS (J)	FACE & CLOSE		SIDESEAM		SERGING	
GROUPS (G)	EXP	CONT	EXP	CONT	EXP	CONT
SUBJECTS (S)	S1, S2	S3, S4	S5, S6	S7, S8	S9, S10	S11, S12
INITIAL TEST [a]	S1, S2	S3, S4	S5, S6	S7, S8	S9, S10	S11, S12
HOUR 1	. .	. .	. .	. .	. .	. .
HOUR 2	. .	. .	. .	. .	. .	. .
HOUR 3	. .	. .	. .	. .	. .	. .
HOUR 4	. .	. .	. .	. .	. .	. .
FOLLOW-UP [b]						
.	. .	. .	. .	. .	. .	. .
.	. .	. .	. .	. .	. .	. .

a- 1/17/90
b- 2/22/90

Video Registration Posture Data

Subjects were videotaped on January 17 (prior to chair introduction) and again on February 22, 1990. Each operator was taped for a minimum of five task cycles. Views of the upper body (head, torso, and upper extremities) and the lower body (lower extremities) were shot separately. All subjects were shot in profile to allow assessment of head, neck, back, and lower extremity postures.

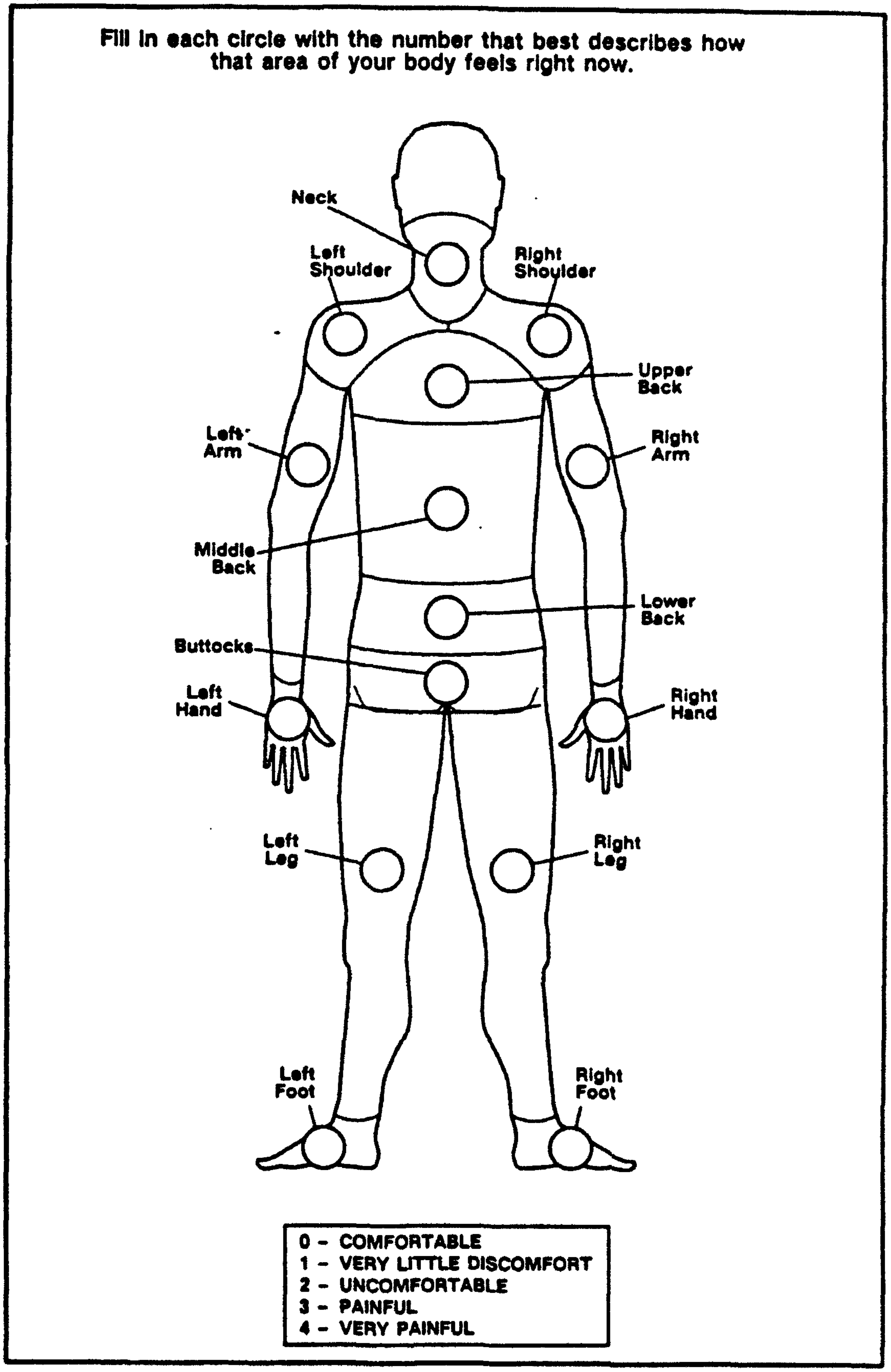


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FIGURE 2. BODY PART MAP COMFORT SURVEY

Production Efficiency Data

Production efficiency data were obtained once per week for two sample weeks before subjects became aware that the study would be conducted, two sample weeks after the follow-up visit and data collection at the site, and six weeks from the initial to the follow-up data collection. Data were obtained from computerized records of weekly production figures from the facility payroll department. Efficiency measures were determined by:

$$\text{Efficiency} = \frac{\text{Units produced X Standard rate (minutes/unit)}}{\text{Minutes worked}}$$

Standard rate was calculated by the plant using a method based on synthetic basic motion times. Table 4 presents the experimental design used for the production efficiency data.

TABLE 4. EXPERIMENTAL DESIGN FOR PRODUCTION DATA

JOBS (J)	FACE & CLOSE		SIDESEAM		SERGING	
GROUPS (G)	EXP	CONT	EXP	CONT	EXP	CONT
SUBJECTS (S)	S1, S2	S3, S4	S5, S6	S7, S8	S9, S10	S11, S12
WEEK 1 [a]	S1, S2	S3, S4	S5, S6	S7, S8	S9, S10	S11, S12
WEEK 2	. .	. .	. .	. .	. .	. .
WEEK 3	. .	. .	. .	. .	. .	. .
.	. .	. .	. .	. .	. .	. .
WEEK 10	. .	. .	. .	. .	. .	. .

a- Week 1: week ending 12/9/89, Week 2: week ending 1/6/90, Week 3-10: week ending 1/20/90- Week ending 3/10/90.

PROCEDURES

One week before the initial data collection the experimenters visited the research site to meet with plant management and engineers to plan the data collection. During this visit, the jobs to be studied were selected. All were seated jobs, used standard height chairs, and had a sufficient number of incumbents to ensure that the required number of volunteers could be easily obtained.

From the pool of volunteers at each position, four subjects were selected with the primary goal of matching the experimental and control groups for age and experience. The selected subjects were randomly assigned to control or experimental conditions.

During the first day of the initial test site visit, the project staff individually briefed the subjects on the study procedures, obtained their written consent, and explained the use of the body part map comfort forms. All subjects were informed that the project might entail some type of workstation adjustment or change, and, initially, no subject was aware of whether they were part of the control or experimental group. Each participant filled out an initial body part map, and the project staff answered any questions or provided any additional instruction that was required.

During Day 2 of the initial data collection visit, subjects were individually videotaped and completed the test body part maps. Subjects filled out one body part map comfort form at 9:00 a.m., 11:00 a.m., 1:30 p.m., and 3:30 p.m.. The forms were distributed approximately 15 minutes before the nominal sampling time. Subjects were instructed to complete the form at the next convenient opportunity (e.g., end of a bundle) within 30 minutes. The completed forms were collected at approximately 15 minutes after the nominal time. Note that the forms took an estimated 1 minute to complete.

On Day 3 of the data collection site visit, each (experimental and control) group met separately with the project staff for approximately 30 minutes. Subjects were all instructed on the important postural concepts in seated work. The control group was made aware of their purpose in the project and received additional training on methods that could be used to adjust their conventional chairs to promote good posture and, potentially, improved comfort. The experimental group members were introduced to the test chair and instructed in its proper use and adjustment. Members of the project staff then met individually with each participant at her workstation to answer any questions and to provide recommendations on chair or workstation adjustments that might be beneficial.

After a period of five weeks, the follow-up data collection was performed. The same protocol was followed for body part map comfort surveys and videotaping on the first and second days. On Day 3, each subject was asked to complete a structured exit interview consisting of a chair feature rating (adapted from Shackel, Chidsey, and Shipley, 1969; Arndt, 1984), an evaluation of the impact of training provided, and, for the experimental group only, questions concerning chair preference and use (See Appendix C). Following the completion of the interview and compensation of the subjects for their participation, a close-out briefing was held with facility management.

Throughout the study period, contact was maintained with subjects through an on-site engineering liaison who relayed feedback from the subjects, reported on conditions at the facility, and transmitted production efficiency data. Production efficiency data were obtained from the facility payroll records.

3. RESULTS

One operator in the experimental group from the face-and-close pockets job withdrew from the study as a result of back, buttocks, and leg pain that she attributed to the test chair. This subject completed all interviews during the follow-up data collection and answered additional questions about her particular experience with the novel chair. Information obtained from this subject is addressed separately in this report. Implications of these findings are discussed in the conclusion.

All other subjects completed the study as scheduled and complete data were obtained from these subjects according to the experimental plan.

MUSCULOSKELETAL DISCOMFORT

Data on musculoskeletal discomfort were taken from the body part comfort surveys that were completed by all subjects at approximately two-hour intervals during one day of the initial test visit and during one day of the follow-up test visit five weeks later. Analyses of the musculoskeletal discomfort data were performed on data from 10 of the 12 subjects. Omitted were data from the experimental group subject who withdrew from the study and data from one Control group subject who reported a drastic increase in level of discomfort in the follow-up test that could not be attributed to any experimental manipulation of this study. Omission of the latter subject tends to make all of the results and conclusions reported in this section more conservative than they would otherwise appear.

Because of peculiarities in the data set, the comfort survey data required transformation before a statistically relevant analysis could be accomplished. This process transformed the data into a dichotomous distribution in which all comfort ratings were recoded as either no discomfort or some level of discomfort. The transformation was required because: (1) with the small number of subjects, individual interpretations of the scale anchors seemed to have inflated the error terms, and (2) in the follow-up data, the experimental group reported no values other than 0 or 1, producing heterogeneous variances between the two groups.

It should be noted that, in the follow-up measurement, only 9 of the 300 ratings given by the experimental group were non-zero; in the control group, 51 were non-zero. This suggests a floor effect, skewed distributions, and heterogeneous variances. Thus, the utility of inferential statistical tests is limited. Inferential tests were, therefore, used sparingly in the data analysis.

The overall effectiveness of the test chair in promoting comfort was investigated by examining the statistical interaction between group membership and time of test on the mean number of discomfort reports per subject. Effectiveness would be demonstrated by equivalent comfort scores between the experimental group and control group during the initial test (during which both groups were using conventional chairs) and a significant comfort advantage for the experimental group in the follow-up test (during which the experimental group was using the test chair.) Indeed, this was the finding. The mean number of discomfort reports per subject, out of a possible 60 ratings (15 body areas X 4 times of the day) was:

	INITIAL TEST	FOLLOW-UP TEST
EXPERIMENTAL GROUP	18.6	1.8
CONTROL GROUP	22.0	10.2

The difference between experimental and control groups in the follow-up test was statistically significant ($p < .05$).

Figure 3 summarizes the mean frequencies of musculoskeletal discomfort reported by the control group in each of the 15 body areas during the initial and follow-up surveys. Figure 4 summarizes these reported initial and follow-up frequencies for the experimental group. Figure 5 summarizes the follow-up data for each of the two groups.

During the initial test surveys, both the experimental and control groups reported increases in discomfort levels as the work day progressed. During the follow-up surveys, the control group continued to demonstrate this pattern with the greatest increase in complaints occurring between 9:00 a.m. and 11:00 a.m.. The experimental group, on the other hand, reported only a slight increase in discomfort across the work day. These data are presented in Figure 6. In the follow-up surveys, the difference between groups was not statistically significant at 9:00 a.m. but was at 11 a.m. ($p<.05$) and 1:30 p.m. ($p<.05$). At 3:30 p.m. the difference between groups approached significance ($p<.06$); given the small sample size, this difference should also be considered real.

Discomfort ratings for the *torso*, *upper extremities* and *lower extremities* were obtained by summing the ratings. The torso consisted of the neck, shoulders, upper back, middle back, and lower back. The upper extremities consisted of the arms and hands. The lower extremities consisted of the buttocks, legs and feet.

Both groups started the follow-up survey day with no upper or lower extremity discomfort. The control group experienced increasing discomfort as the day progressed, but the experimental group did not. In the torso, there was some discomfort all day for both groups, but far less for the experimental group. Analyses of variance were inappropriate for these data because for upper and lower extremities there was no variance to analyze in the experimental group as there was no reported discomfort. All of the nine non-zero discomfort reports by the experimental group during the follow-up were in the torso region.

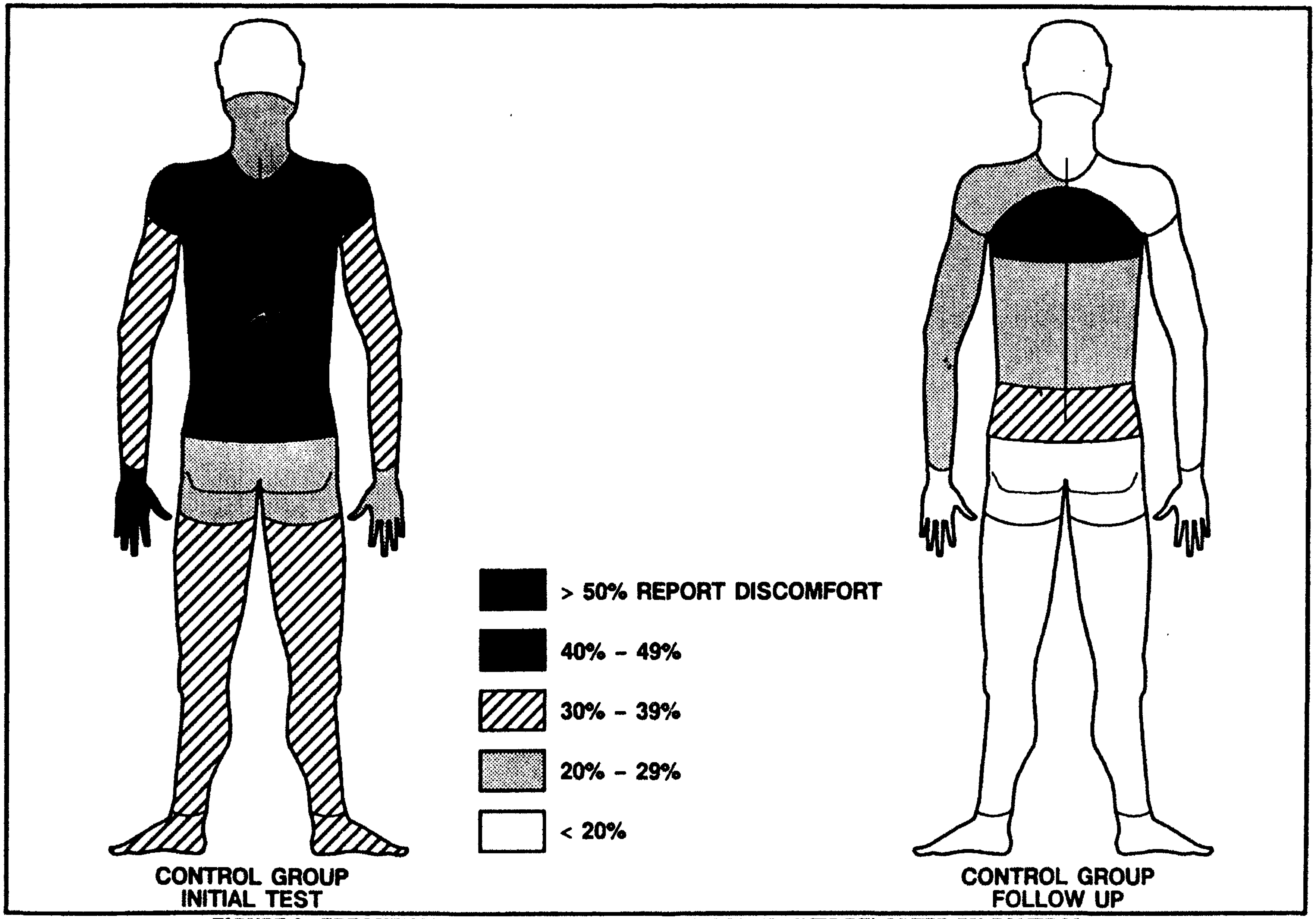

FIGURE 3. FREQUENCIES OF MUSCULOSKELETAL COMPLAINTS REPORTED BY CONTROL GROUP DURING INITIAL TEST AND FOLLOW-UP

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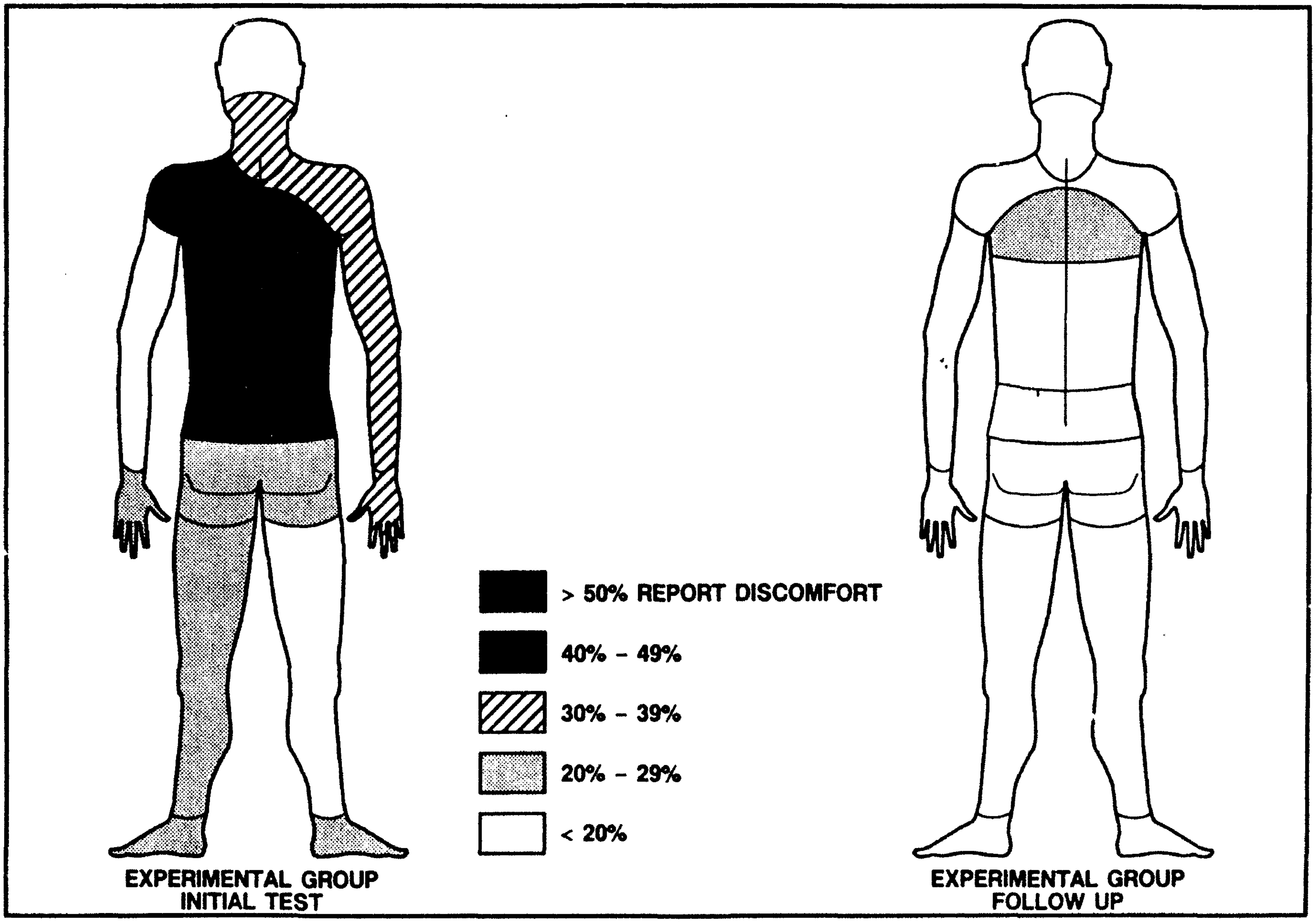

FIGURE 4. FREQUENCIES OF MUSCULOSKELETAL COMPLAINTS REPORTED BY EXPERIMENTAL GROUP DURING INITIAL TEST AND FOLLOW-UP

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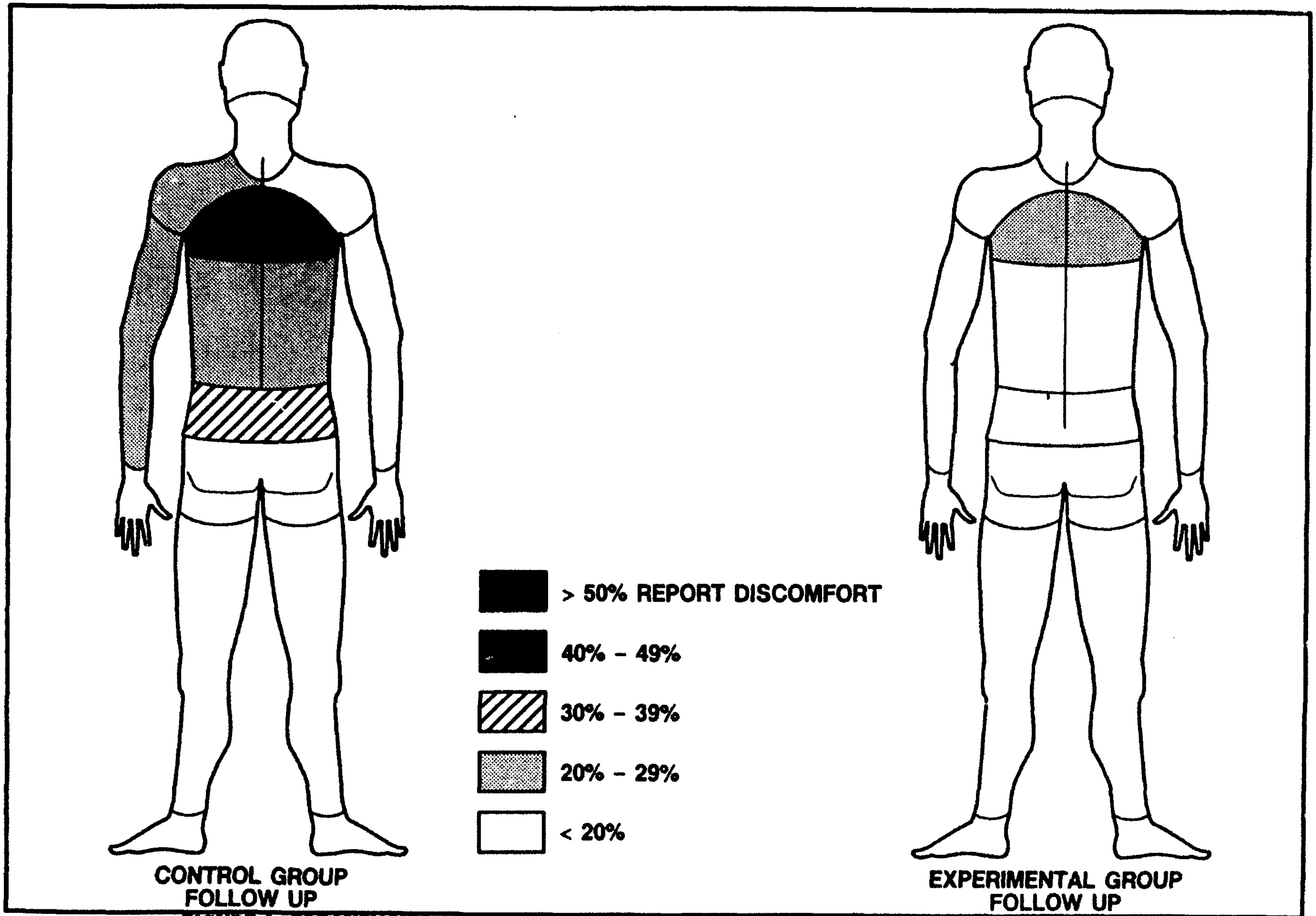

FIGURE 5. FREQUENCIES OF MUSCULOSKELETAL COMPLAINTS REPORTED BY EXPERIMENTAL AND CONTROL GROUPS DURING FOLLOW-UP SURVEY

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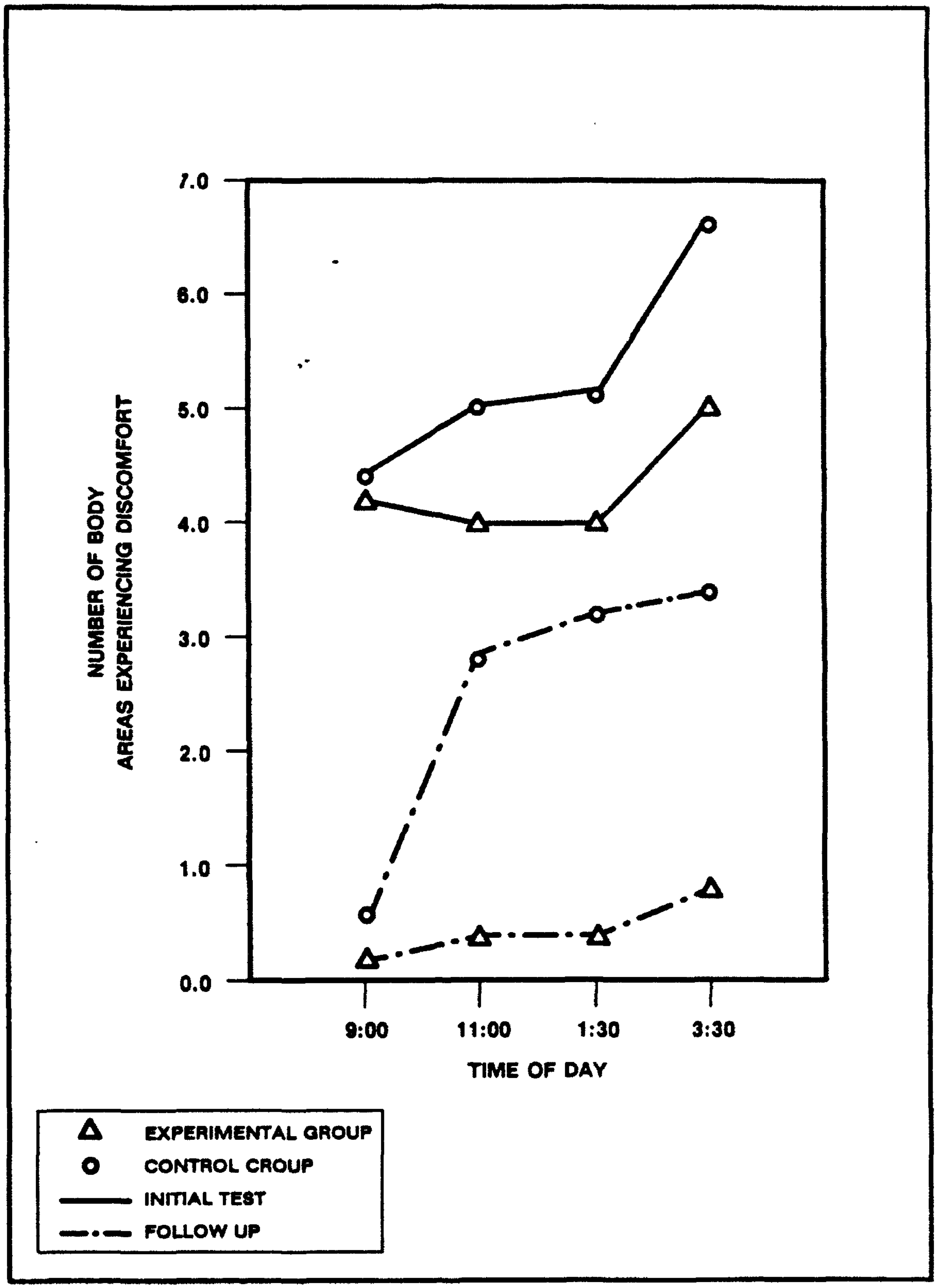

FIGURE 6. FREQUENCIES OF MUSCULOSKELETAL COMPLAINTS ACROSS THE WORKING DAY BY EXPERIMENTAL AND CONTROL GROUPS DURING INITIAL TEST AND FOLLOW-UP

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VIDEO REGISTRATION

Videotape of each subject (including the drop-out) was evaluated qualitatively for changes in behavior and/or posture using a split screen to compare initial and follow-up samples. In addition neck, back, trunk/thigh, and thigh/calf angles were measured directly off the screen using a protractor. The neck or head tilt angle was defined between vertical reference and a line running from the base of the back of the neck through the top of the cranium parallel to the frontal facial plane. The back angle was defined between vertical reference and a line running from the central mass of the buttocks to the shoulder blades.

Behavioral Change

The most noticeable behavior change from the initial to the follow-up sampling period occurred in subjects' contact with the backrest of the chair. Contact was estimated in percent of cycle time. The experimental group increased backrest contact by an average of 44.2% in the new chair. Individual improvement ranged from 0 (N=1) to 100% (N=2). Overall, five of six subjects in this group showed improvement in backrest contact. Contact also improved in the control group but only slightly. The individual improvement ranged from 0 (N=3) to 15% (N=1) with a group mean improvement of only 5.8%. Of the three subjects showing improvement, two were subjects who rated the training and resulting improvement in comfort from their own modifications very high.

Additional subjective assessment indicated that, for those subjects using the backrest properly, hunched posture was reduced. This was attributed to the backrest supporting the operator's maintenance of a more lordotic posture. Typically, muscle fatigue in the low back contributes to the development of kyphotic postures (slumping or hunching).

TABLE 5. CHANGES IN BACKREST CONTACT

Group	Mean	Range	Improved	Worsened	No Change
Exp.	44.2%	0-100%	5	0	1
Ctrl.	5.8%	0-15%	3	0	3

Body Segment Angle Changes

For the discussion of back and head/neck angles which follows, a minimum and maximum (most severe) angle of departure from the vertical was determined for each subject to the nearest 5° increment. The maximum angle was determined to be most representative of posture throughout the cycle. Reported figures reflect changes in the maximum angle measured for each subject.

Back

The experimental group showed a mean improvement of 8.3° in back angle from pre to post measurements. Changes ranged from 0° to 15° with five of six subjects showing some improvement. Again, the control group also exhibited slight improvement with a mean of 2.5°. Individual improvement ranged from 0° to 5° with three of six subjects exhibiting change. Four of six experimental subjects improved by 10° or better, while none of the control group improved by more than 5°.

TABLE 6. CHANGES IN BACK ANGLE

Group	Mean	Range	Improved	Worsened	No Change
Exp.	8.3°	0-15°	5	0	1
Ctrl.	2.5°	0-5°	3	0	3

Head/Neck

This category produced cases where angles worsened. The experimental group improved by only 4.2° with one subject worsening by 10°. Changes ranged from -10° to 25° with two of six subjects improving. The control group worsened by -2.5° with only one subject improving. Changes ranged from -15° to 20° with three of the six subjects worsening.

TABLE 7. CHANGES IN HEAD/NECK ANGLE

Group	Mean	Range	Improved	Worsened	No Change
Exp.	4.2°	(-10)-25°	2	1	3
Ctrl.	(-2.5)°	(-15)-20°	1	3	2

Trunk/Thigh

This category produced the only case where experimental group angles did not improve. The experimental group worsened by 1.7° with two subjects worsening by 10° or more. Changes ranged from -20° to 15° with two of six subjects improving. The control group improved by 0.8° with two subject improving. Changes ranged from -10° to 5° with one of the six subjects worsening. The follow-up mean worst case angles for experimental and control groups were 75.8° and 75.0° respectively. The follow-up mean best case angles for experimental and control groups were 90.0° and 95.0° respectively.

TABLE 8. CHANGES IN TRUNK/THIGH ANGLE

Group	Mean	Range	Improved	Worsened	No Change
Exp.	-1.7°	(-20)-15°	2	2	2
Ctrl.	0.8°	(-10)-5°	2	1	3

Thigh/Calf

Thigh/calf angles remained consistent between individuals in both groups with a mean of 115° and a range of 100° to 135°. No significant changes took place between initial and follow-up data collection periods.

Analysis

With one exception, subjects with worsening head/neck angles in the control group showed improvement in either the backrest contact or back angle categories. This relationship was also noted in the one experimental group subject who worsened in the head/neck angle category. Improvement in the back angle or an increase in the vertical distance to the point of operation (POO) resulting from increased backrest use may have increased the angle of the line of sight thereby contributing to this adaptation.

The trunk/thigh angle results indicate that subjects in both the control and experimental conditions maintained an acute posture throughout the majority of the task cycle. Differences between the groups are slight. It is possible that other workstation factors may have influenced this particular posture aspect. Examples include work surface height, work surface inclination, and reach distance.

Though the between group differences in posture change may not be significant, the important consideration is support. The typical bent posture assumed in seated tasks often causes straightening or even kyphosis in the normally lordotic lumbar region. This increases the stress on the vertebrae and intervertebral discs. The erect posture improves lordosis but requires increased muscle exertion and can contribute to fatigue. The use of a lumbar support such as the one on the test chair can both promote lordosis and relieve the load on the muscles. If the backrest contact data in Table 5 is used as an indicator, the test chair did improve support.

The following information should be considered when reviewing the estimates of backrest contact. The backrest strut on the experimental chair is designed to adjust to up to 10° of forward deviation from the vertical. In addition, the spring-loaded design of the backrest allows it to "follow" the subject when he/she moves forward. However, in the observations on backrest contact, use of this feature was only noted during extreme extension towards the POO (usually once per cycle, short duration) and when the subject straightened to dispose of materials or resets the garment. During the majority of the cycle, the subjects appeared to maintain steady contact with the backrest.

PRODUCTION EFFICIENCY

It was hypothesized that statistically significant changes in production efficiency would be noted due to effects of the training and test chair, to Hawthorne effects (increased motivation in experimental subjects), or to a combination of these factors. For this reason, baseline production efficiency measures were obtained for two representative weeks before the subject operators were made aware of the study. The same data were obtained for the six weeks of the study and for two weeks following the follow-up site visit.

Figure 7 shows the production efficiency for the experimental and control groups during this period. There were no statistically significant trends across time for either group. In addition, the two groups did not experience differential changes that might be attributed to effects of the chair or to motivational effects.

CHAIR PREFERENCE/EXIT INTERVIEW

During the follow-up test exit interviews, all six experimental group operators were questioned about their preference between the test chairs and the conventional operator chairs. The five subjects who completed the study all stated a preference for keeping the test chairs. The one dropout subject preferred the conventional chair.

All subjects rated their chairs (either test or conventional) on seat and backrest height, size, and hardness. The experimental group produced only 2 non-neutral and no extreme responses while the control group produced 15 non-neutral and 9 extreme responses. These responses indicate that the test chair outperformed the conventional chair on these features. Subjects also rated their chair's overall comfort on a 5 point scale anchored with 1= very comfortable and 5= very uncomfortable. The experimental group rated the test chair higher than the control group rated the conventional chair (2 versus 3.5).

Subjects were asked to rate both the value of the training received and whether any changes they had made as a result of it had improved or worsened their overall comfort. Both groups found the training useful to very useful. The experimental group (whose members made almost no workstation adjustments) was neutral on the impact of changes; however, the control group, in which 5 of 6 subjects made several adjustments either to the chair, workstation or both, indicated that overall comfort had at least somewhat improved as a result.

In the difficulty of adjustment categories (experimental group only), subjects unanimously ranked the test chair easy to adjust and easy to learn to adjust. The group also reported a mean initial adjustment frequency of 4.3 times per week for seat height and 6.8 times per week for backrest/seat pan adjustment. The mean frequency dropped to close to 0 times per week in both categories by the follow-up visit.

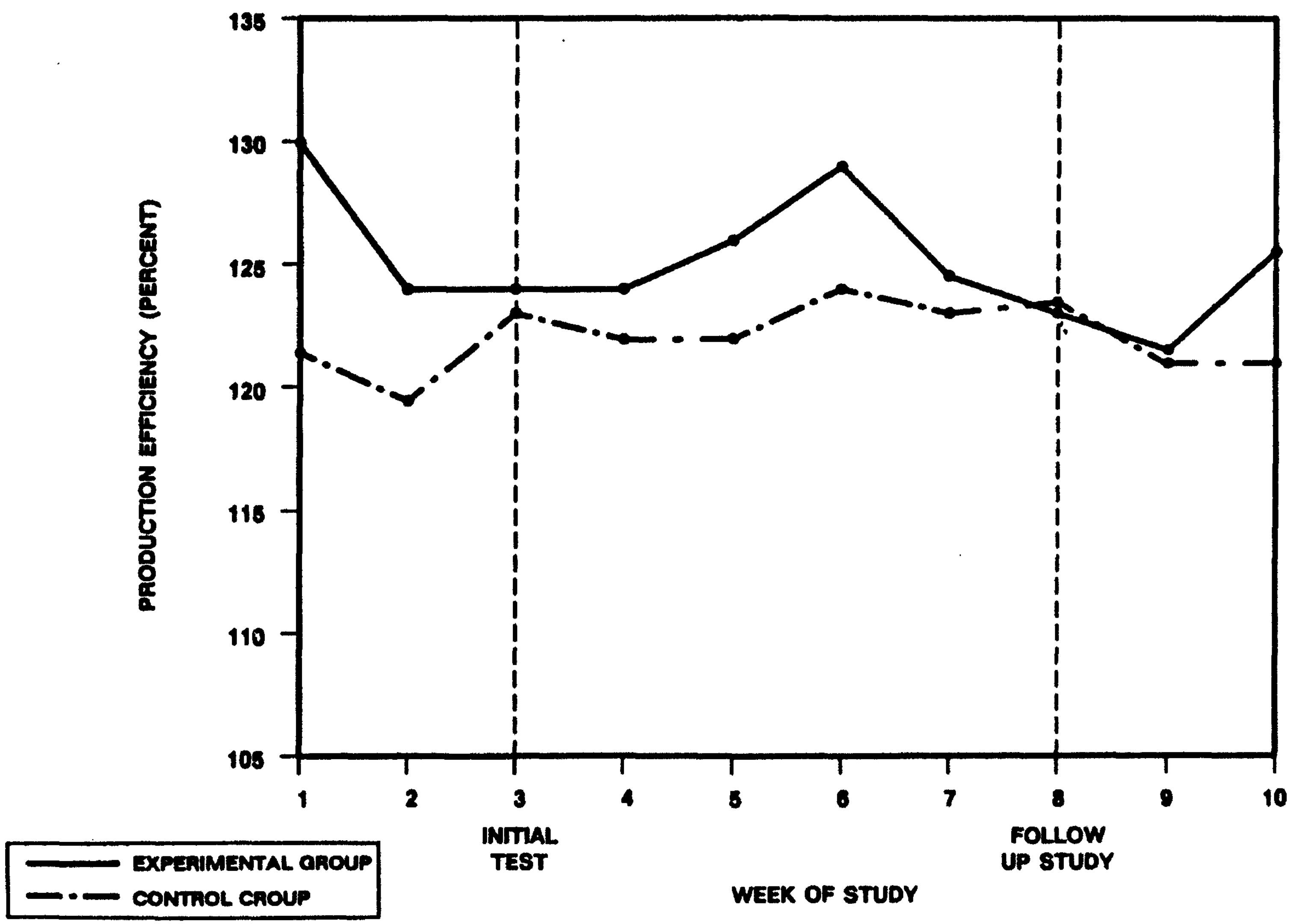

FIGURE 7. PRODUCTION EFFICIENCY OF EXPERIMENTAL AND CONTROL GROUPS DURING 10 WEEKS OF THE STUDY

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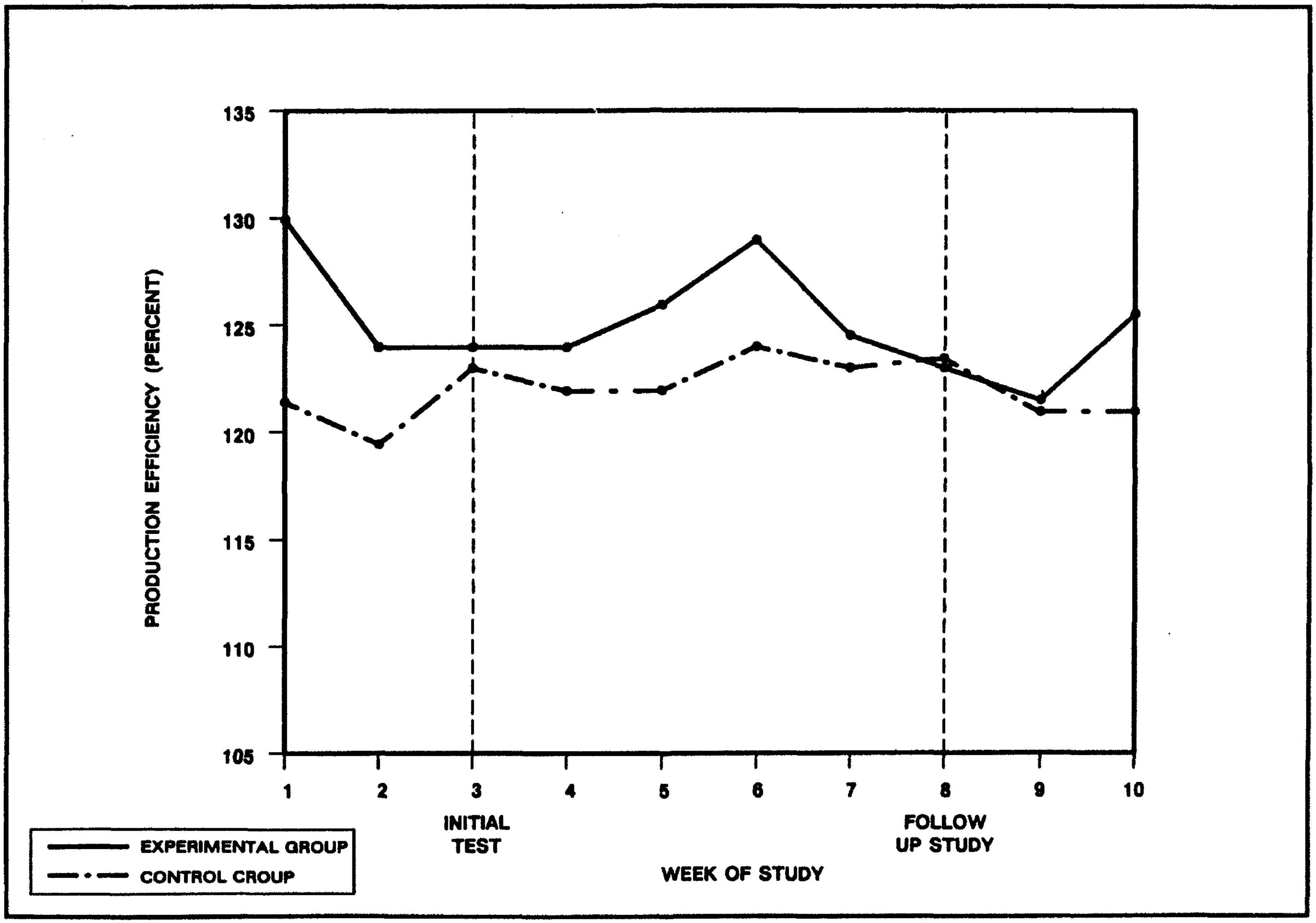

FIGURE 7. PRODUCTION EFFICIENCY OF EXPERIMENTAL AND CONTROL GROUPS DURING 10 WEEKS OF THE STUDY

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THE SINGLE EXCEPTION

In spite of the apparent efficacy of the test chair in promoting operator comfort, some potential difficulty is apparent from the inability of one subject to adapt to the chair. During the first week of the study, this subject reported a sensation of the chair "pushing her out on the floor." This is a somewhat common initial reaction because of the backrest design that allows it to follow the operator through a range of seated postures while maintaining contact. During the second week, the subject reported that she was experiencing lower back pain which she attributed to the chair. At this point, the investigators recommended that the subject discontinue using the test chair. Immediately upon return to the conventional chair, the subject's discomfort returned to pretest levels.

A special interview was conducted with this one dropout subject. She reported that, during her use of the chair, she experienced significant increases in pain across the work day in her lower back, buttocks, and legs. She attributed this to the swivel feature of the chair. She reported no personal or immediate family medical history of musculoskeletal problems. She did indicate that she had sustained a back injury (pulled muscle) in the early 1980's.

This subject did not maintain *any* contact with the backrest on either the conventional or test chair, so the test chair backrest presence would have presumably been much stronger for her. Of all the subjects, she also showed the least change in posture from initial to follow-up testing. It is possible that she countered the swivel movement created by the motion demands of her job with her leg and trunk muscles. This twisting component may have contributed to the discomfort she experienced.

It should be noted that all of the data reports in this section, with the exception of musculoskeletal comfort data, included her results. This exerted some conservative influence on the test chair response levels in the experimental group. However, since it is not possible to discern whether this subject's behavior was representative of a portion of the population or an anomaly, these effects must be taken into account in the interpretation of the data.

4. DISCUSSION

The results provide strong evidence that considerable improvement in operator comfort can be obtained by simple workstation adjustments, posture training, and the use of operator seating that is easily adjustable and specially designed to promote a lordotic posture. However, some limited improvement in operator comfort can also be obtained by providing the training, assistance, and adjusting the conventional seating/workstation. The test chair's impact on backrest contact, a key consideration in the maintenance of lordotic posture and stress relief, is also considerable. However, the impact of the chair on seated posture in this study is somewhat more difficult to discern, while the data suggest that it's impact on performance is not significant.

COMFORT

The results demonstrate a clear and significant departure between the effects of the ergonomically designed chair with training and the effects of training and individual chair modification on operator comfort. While this improvement was not reflected in improved performance (as measured by production efficiency), the long term effects on productivity can be significant.

In developing the comfort assessment method which was also utilized for this study, Corlett and Bishop (1976) illustrated that discomfort experienced in the workplace is frequently an indication of postural stress imposed by poor workstation design. They further indicated that this posturally-linked discomfort was also often symptomatic of musculoskeletal damage and/or disease. While adaptation to the workstation inadequacies was possible, they maintained that many worker adaptations were actually maladaptive and produced undesirable results.

The long term effects of postural stress and maladaptive coping strategies could include lost time injuries or absenteeism and corresponding loss of labor availability and production capacity. From an individual perspective, such incidents would result in a lowered overall production potential across an operator's career.

POSTURE

While the use of the chair appeared to promote improved posture in some categories, the overall impact is difficult to ascertain. The experimental group showed improvement in backrest use and back angle which indicates that the chair may have increased load support and promoted a less stressful, more erect torso configuration. However, the experimental group showed no significant change in overall trunk/thigh angle which remained acute despite the forward tilt capability of the seat pan and adaptability of the backrest. It is possible that these acute postures were developed in response to other workstation deficiencies in such areas as table height, table angle/tilt, reach distances, and treadle position.

PERFORMANCE

The results suggest that the chair had little or no impact on production efficiency. However, production efficiency was utilized as both a dependent variable and a control measure to indicate the presence of Hawthorne effects. Hawthorne effects are discussed below. In addition the efficiency rating utilized did not account for the effects of absenteeism or lost time on production and cannot reflect any improvements in that category.

POTENTIAL CONFOUNDS

Any time research data are collected in the field, rather than in the laboratory, it is difficult to maintain complete control over all factors that might influence the outcome of the experiment. This study was no exception; numerous factors could have confounded the results.

<u>Hawthorne effect.</u> When performing research on human subjects, one of the most important concerns is the motivational factor. The Hawthorne effect (Snow, 1927; Roethlisberger, *et al.*, 1939) is generally defined as an increment in productivity that is related to the motivation of the subjects being studied rather than to the specific independent variables of the experiment. Some subjects simply enjoy taking part in the research; it provides a break from their tedious assembly line work and it temporarily sets them apart from their fellow operators. This often is reflected as higher productivity. In this research, investigators attempted to reduce any confounding due to Hawthorne effect by standardizing interaction with the operators and by de-emphasizing the novel aspects of our activities as well as using a control group. Based on the absence of any systematic changes in production efficiency, the efforts were apparently successful.

<u>Plant reconfiguration.</u> The plant at which data were collected is often reconfigured to reflect slight changes in the design of the product (for example, changing from Army to Marine Corps dress trousers). During the course of the study, two changes were made in the layout of the plant. The Face-and Close operators were moved into a different room in the building. The Side Seaming operators were moved to a different location within the same room in which they were originally tested. The environmental conditions at the first and second locations were very similar and the tasks were unchanged. Nevertheless, the potential effects of these changes cannot be completely discounted.

<u>Placebo effects.</u> Medical doctors have long been aware of the potential effectiveness of a "sugar pill" in addressing many kinds of physical discomfort. When patients expect a treatment to relieve their discomfort, it is much more likely to provide the expected relief. It is possible that the subjects in this study were also influenced by their

expectancy. When distributing the test chairs to the experimental group subjects, the investigators attempted to avoid creating an expectancy that the chairs would promote comfort. It is difficult, however, to evaluate what effects the operator's own expectancies might have had on their experience and follow-up survey responses.

If a placebo effect is present, it would likely be manifested as a tendency to report increased comfort by the experimental group, even for body areas not directly affected by the chair. The body areas least affected by the chair are the hands. Neither group, however, reported much discomfort in the hands. The experimental group demonstrated comfort improvements in every area of the body except the right leg (in which there were no discomfort complaints either pretest or follow-up) as can be seen from Table 9.

TABLE 9. INITIAL TEST AND FOLLOW-UP DISCOMFORT REPORTS BY EXPERIMENTAL GROUP

BODY AREA	INITIAL FREQUENCY	FOLLOW-UP FREQUENCY
Neck	6	0
Right Shoulder	7	0
Left Shoulder	8	2
Right Arm	6	0
Left Arm	3	0
Right Hand	6	0
Left Hand	4	0
Upper Back	14	5
Middle Back	10	1
Lower Back	12	1
Buttocks	5	0
Right Leg	0	0
Left Leg	4	0
Right Foot	4	0
Left Foot	4	0

Individual subjects. Because of the relatively small sample size, aberrations in production by a single operator are visible in the weekly production means for the entire group. During Week 1 and Week 6, the productivity of one experimental group subject, for reasons we were unable to document, rose to unusually high levels. This resulted in performance peaks for the experimental group (Figure 7). During Week 9, this same subject was slightly injured in an accident at home. Her temporary decrement in productivity is reflected by the lowest production efficiency week for the experimental group. During Week 10, her production was approaching its normal levels. Also during Week 8, one experimental group operator was counseled by management about low production. Her subsequent increase in production also contributed to the experimental group's increased production efficiency between Week 8 and Week 10.

The effects of the drop-out on the experimental group were also significant in several categories including posture analysis results, chair preference, and chair feature ratings. The inability of this subject to adapt to the test chair in this study is a rare occurrence that, because of small sample size, produces a statistical anomaly in the data. However, the finding serves to highlight an important conclusion: when novel chairs are introduced into the workplace, some small number of operators may be unable to adapt to them. Therefore, operators should have the option of returning to their original, conventional chairs after a reasonable trial period.

5. CONCLUSIONS

The uncontrolled variables in the factory environment and in the off-duty lives of the experimental subjects made the impact of the ergonomically designed test chair somewhat difficult to assess. The apparently large influence of the test chair on operator comfort may be inflated to some degree by the presence of placebo effects. Nevertheless, there seems to be a very real effect of the chair in reducing reported discomfort in the lower and middle back. The effect on the upper back is more uncertain.

The apparent advantages of the test chair for reducing discomfort in the upper and lower extremities is more difficult to explain. The experimental group reported lower levels of lower extremity discomfort in the initial test. Much of the follow-up survey difference in this category might be attributed to placebo effect. On the other hand, the well-rounded, waterfall front on the test chair presumably allows better circulation in the lower extremities which could be responsible for increased comfort levels.

In interpreting the results of the study, it is important to recognize that discomfort is a highly subjective and complex phenomenon. It is possible that the very real increases in lower and middle back comfort could have very real, indirect effects on the comfort levels of other areas of the body.

From the postural standpoint, the assessment of chair impact was potentially confounded by uncontrolled deficiencies in workstation design. However, it is possible to state that the chair did improve backrest use and, from a qualitative perspective, had a desirable influence on torso posture. These indications, when linked with the improvement noted in operator comfort, indicate the potential benefits of such a chair.

Additional benefits may be realized when this type of chair is applied to operators who serve in a utility status or as part of a seated, modular workforce. In these particular applications, the chair's rapid adjustment capability would facilitate operator adaptation to each workstation configuration. When considered together, all these factors illustrate the value of ergonomically designed equipment and the potential for successful ergonomic intervention in the apparel manufacturing environment.

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APPENDIX A

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APPENDIX B

TEST AND CONVENTIONAL CHAIR DESCRIPTION

CHAIR DESCRIPTION

TEST CHAIR

Seat Pan and Base

The commercially available test chair was designed for ease of adjustability and accommodation of a variety of work postures. The seat pan and back assembly was mounted on a pneumatic cylinder anchored in a four leg base. The pneumatic cylinder allowed for continuous operator adjustment of seat height between 42 cm and 53 cm. The cylinder also self-adjusted (damped) when weight was applied. The net height shift was 2.5 cm under a compression of 90 kg (882 N) at 53 cm initial height. The seat pan measured 39.0 cm in length, 41.4 cm in width, and was concave left to right and slightly convex back to front with a tapered "waterfall" front edge. The pan was padded with approximately 4.5 cm of sponge foam. The seat pan tilt was continuously adjustable between approximately 7° above to 4° below horizontal. The seat had 360° swivel capability.

Backrest

The backrest was attached to a supporting strut which was yoked to the seat pan substructure. The strut attachment collar was spring loaded and allowed the operator to continuously adjust the angle of the backrest from 80° to 106°. This positioned the backrest front edge in a range of 1 cm to 15 cm in from the rear edge of the seat pan. The backrest was slightly trapezoidal in shape and measured 30.5 cm high, 18.5 cm wide at the top and 21.0 cm wide at the bottom. This narrow profile was designed to reduce backrest interference with arm and torso movement (Yu and Keyserling, 1989). The lower half (0 - 14 cm, lumbar section) of the backrest was convex in shape and padded with 6.5 cm of sponge foam in the center. The upper half of the backrest (thoracic section) was relatively flat with roughly 3.8 cm of foam padding. The backrest was spring loaded and mounted on a pivot on the strut. The backrest maintained an approximate angle of 10° to the strut when not loaded. This angle changed as the backrest rotated under pressure applied to the lumbar support through a maximum of 20° until the bottom edge contacted the strut when fully loaded. The spring on the backrest applied roughly 30 N of force in the center of the lumbar support when fully depressed. The vertical location of the backrest was adjustable from 8.5 cm to 21.8 cm above the seat (reference: center of the lumbar support).

Operator Adjustment

The operator adjusted seat height by pulling up on a control lever located on the right side of the chair and releasing the lever at the desired height (See Appendix XXX). The operator adjusted the seat pan tilt and backrest angle by pulling up on a second control lever located 16 cm behind the height control, moving to the desired work position, and releasing the lever. Both actions were accomplished while seated in the chair. The operator adjusted the seatback's vertical position by loosening a knob on the strut collar, moving the seatback and strut to the desired height, and tightening the knob. This action was also achieved while seated or from a potentially more advantageous position behind the chair. No tools were required for adjustment or assembly.

CONVENTIONAL CHAIR

Subjects used their own chairs as controls. Though minor variations in design existed from subject to subject, the chair discussed below represents the majority of the chairs utilized.

Seat Pan and Base

The seat pan and backrest were mounted on four legs. Each leg could be independently adjusted in 2.4 cm increments from 45.0 cm to 64.7 cm. The seat pan was slightly convex from front to back and measured 38.3 cm in length and 37 cm in width. The seat pan was not padded. Seat pan tilt was not adjustable. The seat did not swivel. All of the operators had added some form of cushioning or padding to their chair.

Backrest

The backrest was attached to a supporting strut which bent around the back of the seat pan and attached under the seat. The backrest angle was fixed at roughly 90°. The backrest was trapezoidal in shape and slightly concave from left to right. It measured 15 cm in height, 30.3 cm wide at the top, and 28.3 cm wide at the bottom. The backrest could be adjusted from 0 cm (flush) to 8 cm in from the rear edge of the seat pan. The backrest was not padded; however, some operators added padding. Backrest height was adjustable from 23.6 cm to 28.1 cm above the seat pan (reference: center of backrest, 7.5 cm).

Operator Adjustment

Seat height adjustment required the following:

1) Unscrewing one Phillips-head anchoring screw in each of the legs.

2) Pulling or pushing each leg to the desired increment setting typically assisted by pliers, vice grips, or a hammer.

3) Realigning and screwing the four screws back into each leg.

Backrest height adjustment was accomplished by loosening a hex bolt on the back of the seatback, moving the backrest to the desired height, and retightening the bolt. The backrest proximity adjustment required loosening a wing nut underneath the seat pan, moving the backrest to the desired position, and retightening the wing nut. None of these adjustments could be easily accomplished from a seated position, and the seat height adjustment required getting off the seat. Tools required for adjustment included: a screwdriver, possibly vice grips, pliers, or a hammer for seat height and a wrench or socket wrench for backrest height.

APPENDIX C

EXIT INTERVIEW FORM

Note: Control group members filled out the first page only. Experimental group members continued to subsequent pages.

Subject__________
Date__________

GEORGIA TECH QUESTIONAIRE

Circle the number you choose or fill in the blank where blanks are provided.

1) Please rate your chair on the qualities below.

	too low		about right		too high
a. chair height	1	2	3	4	5
	too soft		about right		too hard
b. hardness of seat	1	2	3	4	5
	too small		about right		too big
c. size of seat	1	2	3	4	5
	too low		about right		too high
d. backrest height	1	2	3	4	5
	too soft		about right		too hard
e. hardness of backrest	1	2	3	4	5
	too small		about right		too big
f. size of backrest	1	2	3	4	5

2. Overall how would you rate your chair:

very comfortable				very uncomfortable
1	2	3	4	5

3. What do you like least about this chair? ______________________________

4. What do you like most about this chair? ______________________________

About the posture training and assistance you received on your chair:

5. How useful was the training and assistance to you?

very useful		somewhat useful		not useful
1	2	3	4	5

6. <u>If you</u> made any changes in your workstation as a result of the training or assistance, what effect did they have on your comfort in your job?

improved		about the same		worsened
1	2	3	4	5

Subject___________
Date_____________

7. Between your previous chair and your current chair, which do you prefer to use in your job? (Your answer will not effect whether you keep the chair or not.)

previous	no preference	current
1	2	3

8. How hard was it to learn to adjust your chair?

easy				difficult
1	2	3	4	5

9. How hard is it to adjust your chair height?

easy				difficult
1	2	3	4	5

10. How hard is it to adjust your seat pan tilt?

easy				difficult
1	2	3	4	5

11. How hard is it to adjust your backrest?

easy				difficult
1	2	3	4	5

PLEASE STOP HERE. GIVE THE FORM TO THE EXPERIMENTER WHO WILL COMPLETE YOUR INTERVIEW.

Subject__________
Date__________

Interview

12. How often did you adjust your chair height during the first week?______________

____

13. How often do you adjust it now? ____________________________________

14. How often did you adjust your seat pan tilt or backrest during the first week?

____

15. How often do you adjust it now? ____________________________________

16. Describe any ways that the chair made your workstation more comfortable:

Less comfortable:

17. Describe any ways that the chair made your job easier:

More difficult:

APPENDIX D

TEST CHAIR ADJUSTMENT INSTRUCTIONS

Note: Instructions based on operation information from chair manufacturer's representative.

ABOUT YOUR NEW CHAIR...

1) Adjusting the height of your chair:

To raise:
- i. Take your weight off the chair while pulling up on the Height Control.
- ii. Let go of Control at desired height.

To lower:
- i. Pull up on Height Control.
- ii. Let go of Control at desired height.

2) Adjusting the seat pan and seat back of your chair:

a. Sit all the way in the seat with your back against the seat back.

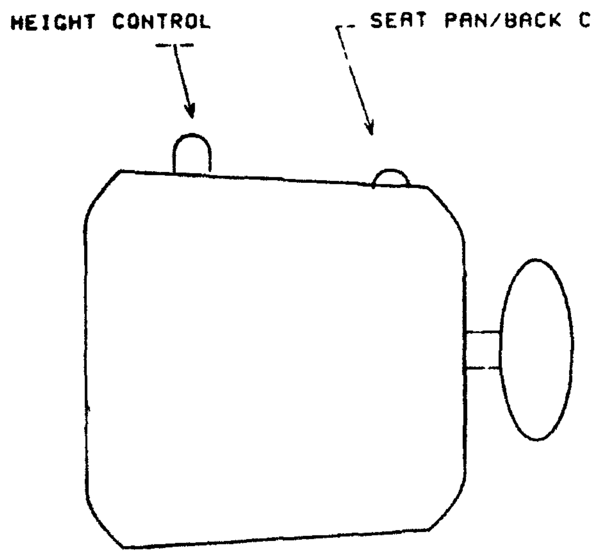
b. Pull up on the Seat Pan/Back Control.

c. Holding the Pan/Back Control, move to whatever position you will be working in.

d. The chair will "follow" you.

e. Let go of the Pan/Back Control to lock the seat in position.

To change position again, repeat steps b - e.



APPENDIX E

PHASE III: EXPLORE HIGHER TECHNOLOGIES

ERGONOMIC CHALLENGERS
IN ADVANCED APPAREL MANUFACTURING

PHASE III REPORT:
Explore Higher Technology Manufacturing Technologies

Research Sponsored by:

U.S. Defense Logistics Agency
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Principal Investigators:

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Georgia Tech Project A-8311

Georgia Institute of Technology
Georgia Tech Research Institute
Environmental Science and Technology Laboratory
Concepts Analysis Laboratory

TABLE OF CONTENTS

Introduction

Some plants, especially the larger ones, are beginning to recognize and address ergonomic and workstation problems through the introduction of relatively advanced manufacturing technologies. These include such approaches as job automation, automated materials handling, ergonomically improved workstations, and the introduction of modular manufacturing cells. Many of these approaches bring with them new or revisited problems and challenges for the ergonomist. During this phase of the program, we explored and documented emerging technologies in the apparel manufacturing industry through experimentation, interviews with equipment manufacturers, apparel manufacturers, and manufacturing personnel.

Automated Materials Handling

In conventional manufacturing operations, boxes of parts and bundles of approximately 40 unfinished garments are carried, dragged, or wheeled on specially designed carts between workstations. Materials movement is done by the operators, themselves, or by designated "bundle boys." Automation of this materials handling process has received a significant amount of attention, perhaps to the detriment of other automation opportunities (see Weissbach, 1986, in Phase I Bibliography). Various vendors are now introducing automated equipment that is designed to make this materials handling more efficient.

A unit production system (UPS), a computer-controlled overhead conveyor, may be used to move hangers of parts or partially assembled garments from one workstation to the next. Rather than large bundles of parts, each hanger typically carries the components of a single garment or a small number of garments.

In one plant that was surveyed, 100 workstations were connected by a typical automated, ceiling-mounted UPS line that carried individual unfinished garments on hangers. A central computer tracked each garment as the bar coded hanger passed by a series of bar code readers on the conveyor line. The garment was automatically moved to the next operation and routed to one of the sewing operators according to the UPS's preprogrammed logic. The garment typically was delivered to the appropriate workstation in a queue near the operator's left shoulder.

Some operators complained about a perceived increase in the noise level and reported temporary auditory threshold shifts during and after the workday. The noise level peaks at the operators' ears, largely produced by impacts between the heavy plastic hangers as they dropped into the queue for the workstation, was measured at between 95 dB and 97 dB at a majority of the workstations. These peaks, occurring every few seconds (depending on the length of the operation cycle at the workstation), were superimposed over a continuous noise level of 82 - 88 dB.

The UPS reduced horizontal reach requirements and all but eliminated heavy lifting by the operators. It resulted, however, in increased vertical reach requirements and increased wrist pronation during acquisition of materials. Interviews on body part discomfort with a sample (n=12) of operators on the conveyor line indicated slightly higher frequencies of hand and leg discomfort among this sample than among their counterparts who utilized conventional materials handling.

Operators on the UPS line expressed dissatisfaction with the "intelligence" of the automated controller. Although the system was designed to be operator paced, faster operators reported that they often experienced empty queues at the same time that work was still being routed to the slower workers. Other difficulties included "ghost hangers" that had dropped their bundles somewhere but were still being moved through the system and counted as units of production.

Perhaps the greatest problem with the UPS was its lack of flexibility and the difficulty in making short-term changes in its logic. Slight changes in the production process, for example reassigning a given workstation to do a different operation for a single day, or temporarily changing the work flow for a short run of a different product could not be done economically. This UPS installation was eventually idled and abandoned when the company changed their product line to a different garment and determined that the UPS could not cost-effectively be altered to support the new product.

Workstation Automation

Many leaders in the industry believe that a solution for some of the training and ergonomic problems lies in partial automation of selected manual manufacturing operations. Automation, for example, can reduce the skill requirements of a complex positioning and guiding task so that novice operators might reach acceptable levels of production within a period of days or weeks rather than the several months currently required. Partial automation can also eliminate many high-risk hand and wrist postures and the frequency of hand movements, thereby reducing the exposure to common repetitive trauma disorders.

There are significant technological barriers to the introduction of complete automation to the sewing workstation. Much of the difficulty is due to the nature of the raw material, fabric. Unlike relatively rigid materials such as metal, plastic, or ceramics, a single ply of fabric is difficult to push or pull or to hold in position with the degree of accuracy required in the manufacturing process. Workstation automation, therefore, must (1) concentrate on operations in which precision is not required, (2) find techniques for making the fabric "act" rigid, and (3) use a hybrid approach in which human operators continue to feed and guide the machines during precise tasks.

Automated cutting machines now being introduced into the industry are programmed to cut stacks of fabric parts precisely and in a given order from a "spread" of 100 or more plies of fabric. By creating a partial vacuum under the porous tabletop, air pressure is used to hold the thick stack of fabric rigidly in place. Cutting of the spread is done automatically by a cutting blade, cutting at speeds up to 2000 cm/minute, under control of the computer.

Partial automation of sewing operations can eliminate some of the risk factors for CTDs. As an example, production of a "felled seam," the kind of double overlapped seam found on the side of denim jeans, requires an awkward posture of wrists, hands, and fingers to hold the fabric in position as it is guided through the sewing machine. This job generally requires over six months of training time and it has a disproportionate incidence of hand and wrist injuries. In recent years, a folding attachment for the sewing machine has become available that guides the fabric edges into the appropriate double-overlapped position eliminating many of the operators' motions and awkward hand postures. A more recent innovation, an automated felled seamer, simplifies the job even further, allowing the operator to use nearly neutral wrist and hand postures throughout the operation. In addition to reducing the incidence of repetitive trauma injuries, this is expected to reduce training time by a substantial amount (Textile Clothing Technology Corporation, 1989).

Workstation Adjustability

Numerous ergonomists (see Wick and Drury, 1986, in Phase I Bibliography) have recommended the use of tilted tabletops to reduce wrist and back angles and to improve visibility during sewing operations. A rapidly adjustable workstation was selected for use in testing this hypothesis. The height of the top was adjustable between 71 cm and 110 cm (28 in and 43 in). The top surface of the workstation could be tilted through angles of +15 degrees through -15 degrees. All adjustments could be made by the operator using a pair of handles below the work surface controlling two hydraulic cylinders. In the Southern Tech AMTC, a Pfaff 463 machine was mounted on the workstation and the operator worked from a seated position. The task performed was attach left fly. Cycle times ranged in the 17 to 25 second range for this inexperienced operator.

Tests of the effectiveness of different tilt angles of the work surface were conducted. The sewing operator assigned to that workstation performed the task at worktable angles of 0 degrees, +15 degrees, and -15 degrees. Videotapes of back and wrist posture were taken as the operator worked and the operator was interviewed at the end of the series of trials. Results indicated no significant difference in wrist or seated postures that could be ascribed to the tabletop angle.

Neck and upper torso flexion (posture change greater than 20 degrees) occurred when the operator pushed the fly through the point of operation. Even though this was a moderately frequent activity, the operator spent from 94 to 100 percent (refer to table below) of the left fly cycle time with a back flexion angle in the erect range of 0 to 20 degrees. From 75 to 85 percent of the work cycle the head tilt (or neck) angle was also in the erect range of 0 to 20 degrees. There was some reduction in the amount of back posture changes per minute associated with table tilt angle (plus or minus 15 degrees), but for the majority of time the operator assumed an erect spinal posture with all workstation configurations and the number of posture changes were not significantly different. Moreover, as the images in Appendix A illustrate, the operator's lower extremity (i.e., upper and lower legs) posture did not change with the angle of the workstation tabletop.

Posture Category	Tilted Away (-15 degrees)	Tilted Forwards (+15 degrees)	Level (0 degrees)
Back Angle (0-20 degrees) Percent of Cycle Erect	94%	98%	100%
Neck Angle (0-20 degrees) Percent of Cycle Erect	79%	75%	85%
Back Posture Changes Per Minute (>20 degrees)	5	4	9
Neck Posture Changes Per Minute (>20 degrees)	12	10	10

As expected, the predominant hand postures were lateral and pulp pinching, flat pressing, ulnar deviation, flexion, extension, and some forearm rotation. Hand activity also remained basically the same across trials. The traditional or level tabletop produced 19.4 right hand and 18.0 left hand motions per minute. With the flexible table tilted toward the operator 15 degrees, the operation was performed with 17.9 right hand and 23.0 left hand motions per minute.

Even though there was not a significant difference in worker posture, the operator expressed a strong preference for positions in which the workstation is tilted forward (i.e., rear edge of the table raised upward). According to her, this particular configuration improved point of operation visibility. Conversely, tilting the workstation away made her more inclined to "feel like leaning forward" to see the point of operation. The results of this study were influenced by high subject awareness concerning appropriate back posture and ergonomics. Consequently, the results are preliminary and anecdotal at best.

Development of a Real-Time Performance Display for the Advanced Sewing Workstation

Introduction

During this task in the program, an initial prototype for a real-time performance display was designed, developed, tested, and enhanced. The prototype display was developed around a color CRT display with a touch-screen interface. It was designed to provide information, throughout the working shift, concerning the operator's production rate and earnings. Production versions of the display concept could be interfaced, as individual workstation terminals, to an appropriately designed real-time production management system on the sewing floor.

Design Goal

The design goal was to develop and demonstrate a means of providing near real-time feedback to the sewing operator concerning her production for the current day, and for the previous few minutes. The prototype system was to be attached to an existing sewing machine workstation and to provide rapid feedback of worker efficiency and earnings using a flexible and easy to use interface.

Rapid feedback of these worker performance measures could be expected to contribute to more rapid and cost-effective skill acquisition during training. Immediate performance feedback is one of the cornerstones of an effective training program for skilled manual tasks such as sewing. The prototype would fill this much ignored need in sewing operator training.

For more experienced operators, a real-time production display system could be expected to promote greater involvement by workers in long term skill maintenance. Immediate feedback could be expected to assist the more experienced operator in continued performance improvement after the completion of the formal training period. During the classic Hawthorne Electric industrial engineering studies, the experimental subjects who showed continued improvement in production were given much more immediate performance feedback than their counterpart comparison groups. Some psychologists now believe that this more immediate feedback, and not the psycho-social aspects of the study, were the real cause of the well known "Hawthorne effect."

Additional information that might be useful to operators, especially during training, could be obtained from an automatically plotted and updated learning curve that could be accessed easily on the display.

For research purposes, it was desirable to implement the prototype visual display in a hardware and software format that it could be easily altered and customized to adopt new design concepts. For the purpose of demonstration, it also had to be independent of any existing shop floor production management systems. Each of these design considerations was translated into specific design objectives.

Specific Design Objectives

Numerous specific design objectives were identified to serve as the basis for the functional specifications of the prototype system. The prototype system was designed to:

(1) Support worker training and development by providing rapid feedback of worker efficiency and earnings and comparison to preset operator performance goals.

(2) Provide a flexible interface that provides methods for the individual worker to easily move from one workstation to another and allows interruptions in work flow (such as lunch or other work breaks).

(3) Support rapid implementation of new design concepts by adopting a modular design which can be easily changed.

(4) Provide these capabilities in a usable interactive visual environment which expresses appropriate human-computer interface design guidelines.

(5) Provide system security through individualized logon codes.

(6) Provide a long-term, time-history display of performance over past weeks or months to allow tracking of performance trends.

Approach

To meet these design objectives, the basic prototype system needed to have graphics capabilities with readily available tools for construction of an interactive visual interface which the user could easily and intuitively alter. A graphical visual display with touch screen interfaced to a stand-alone IBM-PC compatible computer was selected as the development system hardware platform to satisfy these requirements for an usable interactive visual environment. Modular programming software with several off-the-shelf products was selected to implement the user interface, these included: Turbo Pascal version 5.0, Object Professional version 5.0 and Elographics touch screen application generation software. The main display screen created with these tools is depicted in Appendix A illustrating the efficiency graph at the top, today's earnings in the center and the additional options which can be selected by touch at the bottom of the screen.

The implementation was further constrained not to directly interface with the existing manufacturing data management system to allow greater flexibility in implementing display concepts beyond the capabilities of the existing systems. As a consequence, the worker was required to press the "Start Bundle" touch screen zone at the beginning of processing the current bundle and then was required to press the "End Bundle" touch screen zone to register the completion of bundle processing. It is envisioned that, in an implementation of this system, the "Start" and "Stop" functions would be handled automatically through an optical character reader or similar method. This technology is common on currently evolving production management systems.

The benefit to this approach was that the prototype would be self-contained and portable and could be adapted for use with many different manufacturing workstations. Given this basic system, the approach to implementing the remaining design objectives is discussed below.

Supporting training and development

illustrated above, the graphical display of worker efficiency and earnings is presented to the user in the form of two bar graphs: one displaying total efficiency from the beginning of the work shift and the other displaying efficiency in processing the last bundle. Worker efficiency history is also available to the user by selecting the "View Performance History" touch zone. Currently for demonstration purposes the performance history is not based on actual performance but is just a random generation. In the next version, which will reflect the improvements discussed below, a graph of total daily efficiency will be presented for an adjustable period of time, either days or weeks, depending on the amount of worker data that has accumulated to date.

Flexibility and Support of Rapid Implementation of New Design Concepts

Touch zone options for moving to a new workstation, interrupting work, and ending the work shift are all available on the main display within the touch zones.

As already discussed, these capabilities were among the prime consideration in the selection of the prototype development system and are supported through the modular software language and the off-the-shelf interface development tools.

Creating a usable interactive visual environment

Usability concerns the extent to which an end-user is able to carry out required tasks successfully, and without difficulty, using the computer application system. The prototype was evaluated for its usability as a human-computer interface in a number of areas:

> Visual clarity - Information displayed on the screen should be clear, well-organized, unambiguous and easy to read.
>
> Consistency - The way the system looks and works should be consistent at all times
>
> Compatibility - The way the system looks and works should be compatible with user conventions and expectations.
>
> Informative feedback - Users should be given clear, informative feedback on where they are in the system, what actions they have taken, whether these actions have been successful and what actions should be taken next.

Explicitness - The way the system works should be clear to the user.

Appropriate functionality - The system should meet the needs and requirements of users when carrying out tasks.

Flexibility and control - The interface should be sufficiently flexible in structure, in the way information is presented and in terms of what the user can do, to suit the needs and requirement of all users, and to allow them to feel in control of the system.

Error prevention and correction - The system should be designed to minimize the possibility of user error, with build in facilities for detecting and handling those which do occur; users should be able to check their inputs and to correct errors, or potential error situations before the input is processed.

Field Testing, Modifications, and Recommendations

Based on this evaluation and on the comments of operators and vendors of manufacturing systems who viewed the prototype at a recent demonstration, several improvements were recommended for a next-generation prototype. These recommendations and the status of their implementation are discussed in the following paragraphs.

A relatively high rate of errors in alphanumeric input on the touchscreen was noted. It was recommended that alphanumeric feedback should be added to all data entry screens to provide informative feedback and minimize user input errors. This has been implemented in the system software for the current prototype.

The CRT display provides an opportunity to provide significant amounts of additional information to the operator. Task aiding in the form of text and graphics depicting the current sewing task could be added as an additional display to support quality workmanship. This has not been implemented but could be a feature of a next-generation prototype.

For demonstration purposes, there was no existing base of performance data that could be plotted for the time-history record. Fictitious data were used to demonstrate the concept. The capability to record and plot actual time-history data should be included in the next-generation prototype. In addition to presenting the actual performance history, the prototype will retain the capability to present arbitrary history for demonstration and training purposes. These improvements would be implemented in a next-generation prototype.

The system needs to be integrated into a fully functional manufacturing data management system. This involves solving some problems of data compatibility and hardware-software interface issues. This integration testing was reserved for next-generation prototypes.

Technology Integration and Implementation Issues

As discussed above, the prototype is intended to allow creation and evaluation of design concepts which would enhance the existing sewing machine workstations under review in this research effort. If the present prototype were perfected and implemented for manufacturing data management systems, there are several possible approaches to integrating this technology.

Vendors of manufacturing data management systems could add the touch screen hardware, graphics hardware and software capabilities to their existing systems. This would require these vendors writing their own display support software compatible with their software environment. Although the best possible integration of the technology, it also is the most expensive. Next generation manufacturing data management systems could adopt the display standard. Obviously no present systems would benefit from this but it would be a cost effective approach.

An existing manufacturing data management system could run in parallel with the prototype system. Since the prototype system does not directly interface with any existing manufacturing data management system, at a minimum, capabilities would need to be added to allow sensing of bundle processing. Therefore, rather than requiring workers record the beginning and end of bundle processing manually, interface to the appropriate sensor could be added to relieve the worker of this task. A customized IBM-PC could be developed taking advantage of the lower per unit cost of IBM-PCs and the modest requirements for the software/hardware platform. One benefit to this approach is that the prototype would be continue to be self-contained and could be adapted for use with many different manufacturing workstations. However, because of the number of integration factors it is difficult to evaluate the cost effectiveness of this approach.

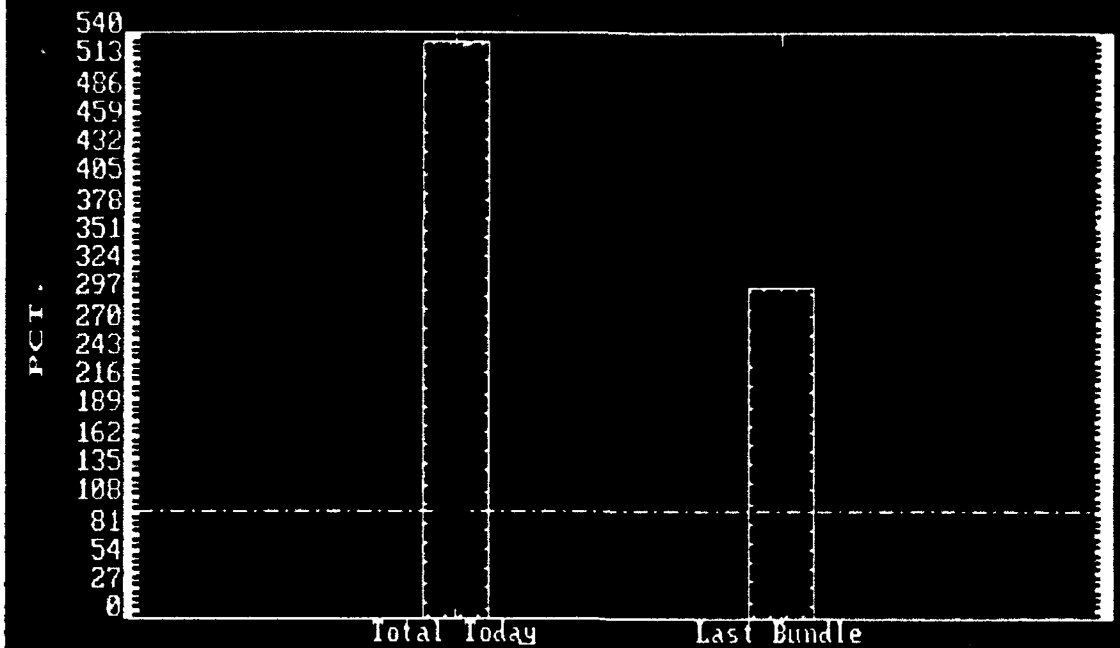
Operator Real-Time Information System

Operators who receive near-real-time information feedback about the level of their performance might be expected, according to behavioral principles, to improve their performance. Real-time production management systems are reaching the work floor to track the location and flow of particular bundles, and the status and performance of individual workstations. Terminals at each individual workstation are connected to a central computer system. Managers and supervisors have access to this information to aid in production management and planning. Similar data may be available on the terminals at each workstation but it is not easily obtained and interpreted.

GTRI designed and prototyped a real-time display system that would allow the operator to establish production goals and would provide the operator with continuous information, in bar-graph form, of progress toward meeting the established goals. A touch-screen system on the small color monitor could be used to sign on and off, establish goals, change goals, determine total earnings and projected earnings for the day, and perform other display-control functions. The real-time display system could be integrated with the information network on a real-time production management system, like those currently in existence, to provide these data at selected workstations. The system would be most cost-effective if used in conjunction with operator training and retraining.

APPENDIX A
Video-Analysis Images

APPENDIX B
Real-Time Display Screen



Worker Efficiency (current totals)

Today's Earnings $12.01

Move to New Station	ON Break	End of Shift	Start Bundle	Change Performance Goal	View Performance History

APPENDIX F

PHASE IV: TRAINING VIDEO AND MANUAL

The Ergonomic Training Video and Workbook are contained on the inside back cover of this binder.

APPENDIX G

MODULAR MANUFACTURING SYSTEMS

DESIGN AND DEVELOPMENT OF A SELF STUDY COURSE FOR APPAREL SUPERVISORS IN THE PRACTICAL APPLICATION OF ERGONOMIC PRINCIPLES

PHASE V REPORT: APPLICATION OF ERGONOMIC PRINCIPLES TO MODULAR MANUFACTURING SYSTEMS

Research Sponsored by:

U.S. Defense Logistics Agency
(DLA900-87-D-0018-005)

Principal Investigators:

Daniel J. Ortiz, Project Director and Technical Co-director
Michael J. Kelly, Technical Co-director
Theodore K. Courtney, Research Engineer I
Tymas Aristotelis, Graduate Research Assistant

Georgia Tech Project A-8311

Georgia Institute of Technology
Georgia Tech Research Institute
Environmental Science and Technology Laboratory
Concepts Analysis Laboratory

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TABLE OF CONTENTS

TABLES AND FIGURES

BACKGROUND AND INTRODUCTION

There are currently significant efforts under way to eliminate the progressive bundle assembly-line process and to introduce the concepts of modular manufacturing cells into the apparel manufacturing workplace. In this concept, a complete garment (or major sub-assembly) is produced in a modular cell of, perhaps, a machine to operator ratio of two to one. Operators are not assigned to a single operation but may move between workstations as the flow of product requires. Individual workstations are typically shared by two or more operators.

In contrast to traditional management practices, the team of operators in the cell is responsible for many elements of workflow planning and management, team formation and interpersonal relations, and product quality. Because modular cells are rapidly reconfigurable, modular manufacturing has been promoted as an efficient way of providing a quick response to the common need for a short production run of a particular product.

Because there is no real standard for the design and implementation of modular cells, numerous alternative configurations have been implemented. Modules with as few as four operators and as many as twenty were found. In some configurations observed during this study, modular cells more closely resembled small progressive bundle plants. The number of operators approximated the number of sewing positions and most operators would sit at a particular position for hours at a stretch. Only two or three operators might move between stations. Other implementations were derivations of the Toyota system. There were, perhaps half as many operators as sewing positions and the cross-trained operators constantly moved between the (typically) standing positions as the flow of product required.

Attempts to introduce modular manufacturing have produced inconsistent results with both notable successes and distressing failures. Anecdotal reports suggest that, after a period of adjustment, many workers experience significantly decreased levels of musculoskeletal discomfort due to the increased variety in movements, to improved postures at the standing workstations, and to motivational factors. Increased morale and workgroup cohesiveness, along with substantially reduced absenteeism, have also been seen in successful implementations.

Numerous ergonomic questions and challenges appear during the implementation of the modular system. Many traditional workstations will need to be redesigned. Increased adjustability/adaptability will be required for workstations that are shared by two or more operators. Issues of job design, training, organizational design, performance assessment and reimbursement will need to be successfully addressed.

As one example of ergonomic issues in workstation design, some implementations of modular cells have required a switch from a primarily sitting workplace to a primarily standing workplace because of the need for operators to move between the workstations in the module. This may necessitate redesign of machine controls since the traditional sewing machine foot treadles are not usable from a standing position. It was not known whether existing standing foot controllers provide the necessary level of sensitivity for precise machine control. Several designs of new foot-actuated controllers have recently been introduced but none has proven entirely satisfactory.

In unsuccessful attempts at implementation of modular manufacturing, reduced individual production is often attributed to the lack of specialization by operators and to less efficient material handling techniques. Inability to effectively plan and manage production within the cell, interpersonal problems, and dissatisfaction with new group-incentive pay schemes are also cited as problems. In contrast to expectations, one company terminated its attempts to implement modular cells when they found that short production runs could be done more effectively using their progressive bundle system because of reduced cross-training requirements. Other ergonomic problems related to job, workstation, and workgroup organization are certain to become apparent as the apparel industry's experience with modular manufacturing systems expands. A detailed exploration of these ergonomic problems was needed to identify and address these issues.

The purpose of this study was to examine case studies of both successful and unsuccessful attempts to institute modular manufacturing systems in apparel manufacturing plants in the southeastern United States. Because the perspectives of management and sewing operators were potentially different, it was necessary to interview representatives of both groups of individuals in order to obtain an unbiased view of the advantages and problems in the implementation of modular manufacturing systems.

METHODS

Overall, the protocols used in this phase follow closely those used in Phase I (Ortiz, 1989). Comparisons are frequently made to the Phase I results when appropriate to gain incite into the differences and similarities that may exist between the traditional progressive bundle and modular manufacturing approaches. The same approach is used to compare and contrast seated versus standing and dynamic versus static work.

Interview

Modular and traditional employees from two Southeastern United States apparel manufacturing plants (Plants A and B) were selected for interview on a strictly voluntary basis. Interviews were held during work and required approximately 20 minutes of each participant's time. A total of 79 employees participated in the interview process (12 males and 67 females).

Detailed employee interviews were conducted with all participants using the structured questionnaire in Appendix A. The participants were assured that their responses would be held confidential, and their names were not placed on the interview forms. Interviews were held in closed offices or areas isolated from the production floor to encourage candor in the responses. The interviews covered the following areas:

1) Demographic information
2) Musculoskeletal injuries and discomfort
3) Workstation characteristics
4) Training and worker attitudes
5) Work schedule and system of payment

Managers and engineers were also interviewed to obtain their view of the effects of converting to modular from a progressive bundle handling system on human performance and productivity.

Workstation and Worker Measurements
Twenty-one (N=21) representative jobs within Plant A module 1 were selected for video analysis and posture documentation. To approximate the between station movement frequency, worker movement was quantified in two three minute sample periods. A movement activity was scored when a worker took two or more steps between tasks. A digital dynamometer was used to measure the forces required to actuate the machines in Plant A module 1 and Plant B module 13.

Worker elbow height was the only anthropometric measure taken. This was compared to the height of the work (point of operation) in both Plant A and Plant B modules 1 and 13, respectively. A Gossen-Panlux light meter was used to measure the illuminance on the work surface (i.e., point of operation) at both plant locations.

PLANT AND WORKER DEMOGRAPHICS

Site visits were conducted at three manufacturing plants located in the Southeastern United States. Two plants (Plants A and B) each with approximately 350 employees were selected for detailed analysis due to their use of modular cells in the workplace. A third plant, representing an unsuccessful attempt at modular manufacturing, was selected for management interview only. Plant A manufactures dress trousers and Plant B manufactures shirts. A detailed description of both plants is provided as follows.

Plant A
Plant A is comprised of 13 standing modules involved in the assembly of various trouser product lines. Within each module their are approximately 22 workstations arranged in a U-shaped configuration and 13 machine operators producing a workstation to worker ratio of 1.7 to 1.0 (22/13). One person is usually trained on three machines, one in either direction of their primary job. Workers generally move forward with the garment (within capabilities) and have fewer than five garments in process in what is almost a hand-off system of assembly. A modified bonus system of payment that is a hybrid of hourly plus group incentive methods of payment was in use at the time of the survey. This company

began converting to standing modules in August, 1990.

Plant B

Plant B (shirts) has 12 sitting modules and two standing modules. The typical sitting module has 12 workstations and 11 machine operators. The two standing modules have 16 workstations and 8 machine operators (2.0 to 1.0 ratio). Modules are arranged in a linear configuration with two identical lines per cell and workers are trained to do three or four machine operations.

A Kanban system is in use at the standing modules (Monden, 1991). When the five pair supply Kanban is full the operator moves forward (within capabilities) and will bump operators from subsequent operations. The seated modules use a traditional manual bundle handling system. This facility has a group incentive system of payment and began converting to modular in 1991, six months before the site visit.

General Information

A total of 79 apparel manufacturing workers were interviewed during this study. Of those 67 were female and 12 male (all from Plant B). Referring to Table 1 shows that female workers who participated in Phase V were younger and had less total experience than the Phase I study population. Plant A and Plant B female workers were however similar in all three categories. Unlike Plant A, Plant B standing modules had a significant number of male operators representing more than one third of the cell population. All Plant A employees interviewed (N=42) occupied standing jobs (modular and traditional). Sixteen of the Plant B female workers interviewed (N=25) occupied seated tasks, four occupied standing modular tasks, and five indicated that they have jobs that permit both sitting and standing. All the males (N=12) occupied standing jobs with eight occupying modular sewing operations.

Table 1. Worker age and experience.

Study Population	Average Age (years)	Average Experience (months)	Average Modular Experience
Phase I Female (N=123)	40	103	0
Phase V Plant A Female (N=42)	32	83	12
Phase V Plant B Female (N=25)	32	86	10
Phase V Plant B Male (N=12)	28	54	6

RESULTS

Dynamic and Static Work

Static muscular exertions (e.g., standing in one place, prolonged sitting, holding arms extended) are associated with prolonged contraction of the muscles. Prolonged muscular contractions can restrict blood flow and impede the working muscle's ability to acquire nutrients and eliminate waste products. On the other hand, dynamic work (e.g., walking and running) is characterized by rhythmic changes in the muscle between relaxation and exertion and contraction and extension that actually promotes blood circulation (Grandjean, 1982). Static muscular exertions are physiologically less efficient and anatomically more stressful than similar dynamic work. For example, prolonged standing can create static loads on the leg muscles restricting blood flow and causing the accumulation of fatigue producing metabolites. Moreover, the pooling of venous blood in the lower extremities that occurs when the leg muscles remain in a contracted state for long periods also contributes to worker pain and discomfort.

Most apparel jobs and jobs in general have static and dynamic components. For example seated and standing sewing operations usually involve highly repetitive (i.e., dynamic) movements of the hands and arms with decreasingly fewer movements of the torso and lower extremities (i.e., larger static component).

To measure the level of static and dynamic activity within the modular cells, movement patterns were noted at both Plants A and B during two three minute sample periods. A movement was scored if a worker took two or more steps to accomplish the task. Twelve workers from Plant A belt loops and back pockets were selected to represent static standing jobs based on the finding that workers committed an average of only 0.3 movements per minute. The remaining thirty workers that participated in the interview from Plant A were from standing modules where there was much greater movement activity (i.e.,larger dynamic component). Workers from Module 1 made 2.2 movements per minute with all but 4 of the 13 workers committing at least 1 movement per minute.

Plant B seated modular cell female workers (N = 16) are indistinguishable from the Phase I traditional seated study population based on movement opportunity and activity. Only two to four workers per cell operated more than one machine. This translated into a large static component where the average movement activity was 0.1 movements per minute per person. Module 13 was substantially more dynamic with standing modular workers committing 0.5 movements per minute. A total of eight males and four females were interviewed from the Plant B standing modules. Only one worker from the standing module did not move during the sample periods.

Postural Discomfort

As discussed in the foregoing section, static exertions such as prolonged standing and sitting are associated with muscle fatigue and body part discomfort (Grandjean, 1982 and Van Wely, 1970). Standing work is often associated with discomfort to the legs and feet whereas seated work is often associated with discomfort to the trunk and shoulders due to the prevalent use of hunched postures by machine operators. Whereas standing may allow a worker to assume a more upright and stable spinal configuration than sitting it requires a greater energy expenditure to maintain the weight of the upper torso. From an industrial engineering standpoint standing is preferred over sitting when the range of motion required by the job is outside the worker's normal reach envelope (Eastman Kodak, 1983).

Worker preference regarding seated versus standing work depends on prior experience with either or both types of workstation(s). Over 75 percent of the standing workers interviewed (with most having past experience at conventional seated workstations) preferred standing over sitting . Seated workers with no standing sewing experience preferred sitting over standing by a margin of 48 to 9 percent. Furthermore, a large proportion of seated workers (43%) would prefer to do both even though they had no prior experience using a sit-stand workstation. These results suggest that lack of standing work experience might influence attitudes toward and the acceptance of the stand-up modular approach.

In theory, frequent between station activity that reduces the duration of static muscular exertions might improve work tolerance (Chaffin, 1973). Many ergonomists recommend a workstation that allows individuals to alternate between sitting and standing. Such a workstation might reduce static loading of the different muscle groups and perhaps help maintain the structural integrity of the intervertebral discs due to the change in disc pressure that accompanies the recommended posture change (Grandjean, 1982).

In a European study conducted with supermarket female workers the prevalence of lower extremity discomfort increased as the time on their feet (standing in one place) increased (Ryan, 1989 and NIOSH, 1992). Therefore, it is reasonable to assume that increased dynamic activity associated with modular work cells should be reflected in the comfort data.

Using the procedures described in the Methods Section, a total of 79 employees from Plants A and B rated the frequency with which they experience postural discomfort, that might be related to their jobs, in each of 16 body parts. Workers were asked to enter a "1" if they experience discomfort "never", a "2" if "sometimes", "3" if "frequently", and "4" if "constantly" for each body part. Although useful in detecting workstation incompatibilities it is important to be aware of the fact that discomfort data are subject to many biases including between subject variation in the perceived level of pain, the effect due to Hawthorne, and organizational influences (Ortiz, 1989).

Phase I Versus Phase V

Figure 1 is the overall comparison of Phase I (PI)(N=123) and Phase V (PV)(N=65) female respondent comfort results. The upper extremity region includes the right hand (RH), left hand (LH), right arm (RA), left arm (LA), right shoulder (RS), and left shoulder (LS). The lower extremities are graphically represented by RF (right foot), LF (left foot), RK (right knee), LK (left knee), RL (right leg), and LL (left leg). Finally, the trunk region is represented by LB (low back), MB (middle back), UB (upper back), and N (neck). The top two graphs represent the average discomfort level (average score on a 1 to 4 scale) for each body part and the bottom two graphs represent the frequency of respondents reporting discomfort at least "sometimes" (a "2" or greater on the body part questionnaire).

There is a high correlation between discomfort level and discomfort frequency ($r^2 > 0.95$ for both Phase I and Phase V data). Over 45 percent of the Phase V respondents reported discomfort to the right hand (45%), right foot (48%), left foot (45%), upper back (54%), middle back (46%), lower back (63%), and neck (61%). Discomfort levels were also greatest about the right hand (1.70), right foot (1.71), left foot (1.77), upper back (1.83), middle back (1.68), lower back (2.01), and neck (1.94).

There is little correlation between the Phase data ($r^2 = 0.23$ for discomfort levels and 0.30 for discomfort frequencies) with major differences on the lower extremities, lower back, and neck . The upper extremity discomfort profile is, however, similar. The following analyses help resolve the differences and similarities between study groups .

Phase I Versus Plant A and Plant B

Figure 2 compares the results of the comfort study (female only) from the individual modular plants and the Phase I data. UEAVG represents the average of the six upper extremity body parts (hands, arms, and shoulders). LEAVG represents the six lower extremity body parts (feet, legs, and knees). TRAVG represents the average of the trunk body parts (low, middle, and upper back and neck). OVAVG is the total average of the 16 body parts for each subject population. The first four histograms represent the average discomfort scores for each body region (UEAVG, LEAVG, TRAVG, OVAVG) and the next four represent the average prevalence of discomfort reports (%UEAVG, %LEAVG, %TRAVG, %OVAVG).

Plant A stand-up modular respondents had a slightly lower level of upper extremity (UEAVG) and significantly higher level of lower extremity (LEAVG) discomfort than Phase I and Plant B. Plant B and Phase I were predominantly static seated operations which helps explain the similarity in comfort levels (see Table 2 below for correlation values) except for the greater level of reported trunk discomfort (TRAVG) among the Plant B study population. Overall, the average discomfort level and frequency were greatest among the Plant A respondents due largely to the lower extremity results.

Table 2. Body part discomfort level correlation (r^2) between Phase 1, Plant A, and Plant B interview sites.

	Phase I	Plant A	Plant B
Phase I	1.00		
Plant A	0.01	1.00	
Plant B	0.54	0.01	1.00

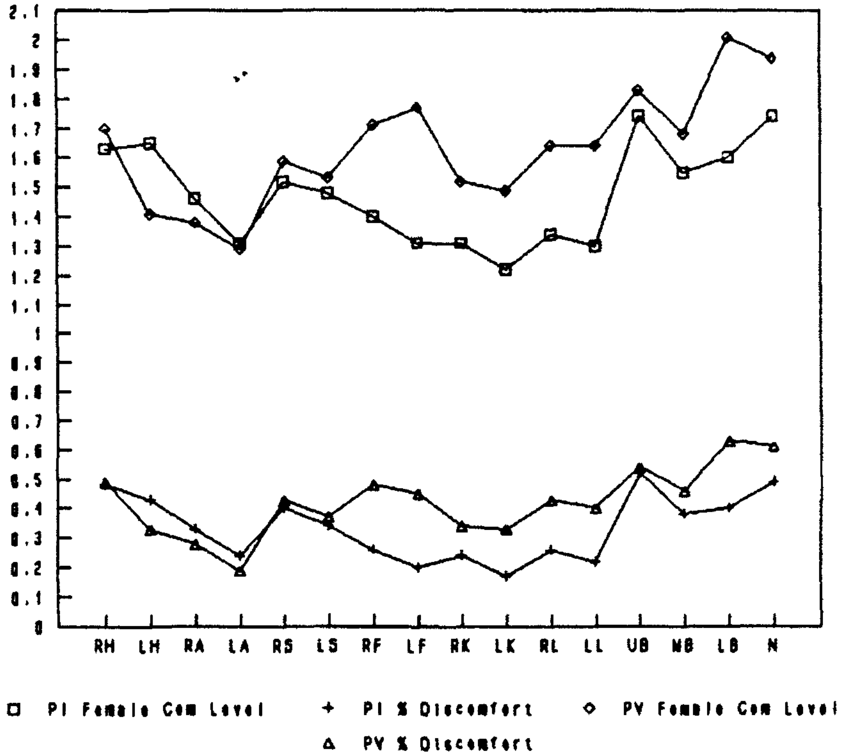

Figure 1. Phase I and Phase V overall female discomfort comparison.

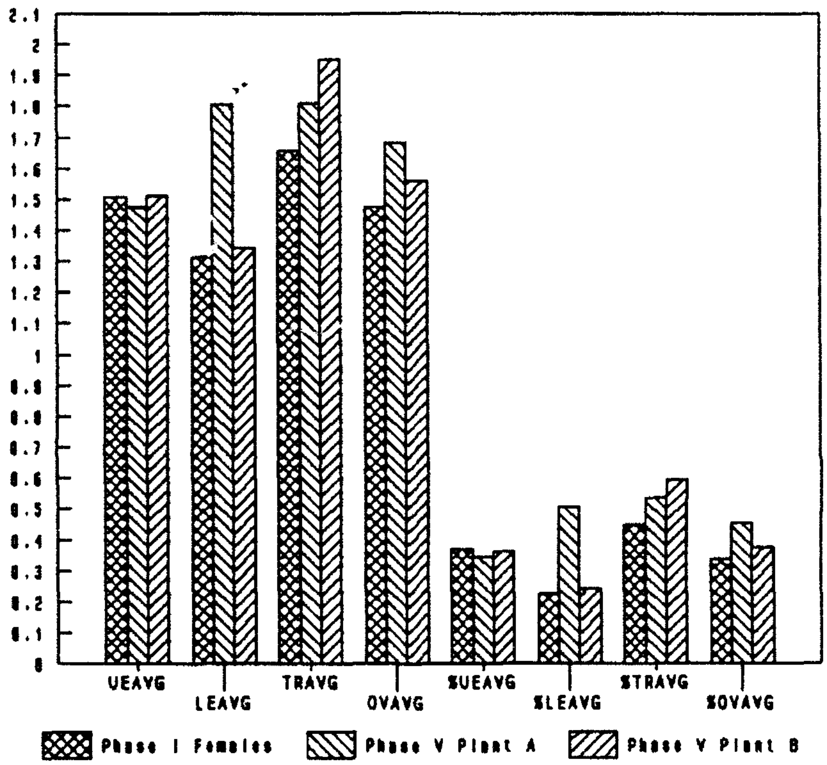

Figure 2. Comparison of Phase I (PI), Phase V Plant A (PVA), and Phase V Plant B comfort data by body region. (The first four sets of bars are discomfort score averages and the next four represent average discomfort frequencies.)

Phase I Seated Versus Plant B Seated Modular Respondents
In Figure 3 a comparison is made between Phase I and Plant B seated female respondents. There was very little movement opportunity associated with the Plant B seated modules so they are, like the Phase I seated operations, defined as primarily static operations with respect to the trunk and lower extremities. The major differences were discomfort to the left hand (LH), right shoulder (RS) and low back (LB) and neck (N).

The higher shoulder and trunk discomfort levels and frequencies reported by the Plant B operators can be partially explained by the greater level of between station manual bundle handling at this location. The Phase I plants typically transferred bundles between station with the use of carts, horses, and/or clamp trucks. There were similarities between the subject populations about the lower extremities that helps explain the discomfort level correlation coefficient of 0.49.

Phase I Seated Versus Plant A Standing Modular Respondents
In Figure 4 a comparison is made between the standing Plant A modular employees and seated Phase I progressive bundle system trouser manufacturing employees. There was little correlation between the female only comfort data (r^2 = 0.15). Large differences exist on the lower extremities where Plant A standing modular respondents had much higher levels and frequencies of complaints than the traditional Phase I seated study population .

Closer examination of the data reveals that the lower extremity discomfort levels reported by modular standing workers is asymmetrical and focused on the noncontrol using foot, knee, and leg (i.e., entire left side). This finding lends credence to a textbook concept that foot controls should not be used in standing work because they can produce an asymmetrical load distribution on the lower extremities with most of the operator's weight supported by the noncontrol using foot (Konz, 1983 and Grandjean, 1982).

It is reasonable to assume that frequent between station movement might contribute to improved upper extremity comfort if it provides a brief respite from the hand intensive repetitive work and the hands are not involved in holding and material handling activities during the activity. Moreover, dividing time between tasks with different levels of hand activity might help improve worker upper extremity comfort. With greater movement and less hand activity, Plant A modular respondents had only slightly lower reported levels of discomfort to the upper extremities and similar trunk discomfort profiles as the Phase I group.

Plant B Standing Male Versus Seated Female Modular Workers
From Figure 5 it is apparent that there is very little comfort level correlation between seated female and standing male modular workers interviewed at Plant B (r^2=.002). Conversely, the stand-up modular male workers (N=8) from Plant B exhibited a discomfort profile similar to the stand-up modular workers from Plant A (r^2=0.32) with most of their discomfort focused on the lower extremities as well. Over half the male respondents reported discomfort at least sometimes to their feet, knees, and left leg.

The male discomfort level was highly correlated with the frequency results and like the Plant A standing module data there is an asymmetrical discomfort level pattern associated with the lower extremities focused on the left extremity. With only eight male standing modular subjects one can only speculate on the significance of these results. But clearly the common denominator associated with both Phase V Plant A and Plant B modular standing workstations that might explain this discomfort profile is the use of a pneumatic, electric, and/or mechanical foot control.

With even fewer female standing modular workers (N=4) we did not include them in the detailed analysis. All four subjects reported no discomfort (a "1" on the comfort scale) to the six upper extremity body parts. As with their male counterparts, much of their discomfort focused on the lower extremities, with their feet as the major area of concern.

Plant A, Plant B and Phase I Standing Worker Comparisons

The Figure 6 bar graphs suggest that even with greater between station movement, foot control users from Plant A (PVA Mod Stand) and Plant B (PVB Mod Stand) had a slightly higher average lower extremity discomfort level (LEAVG) than the static standing population that did not use foot controls (PVA Static Stand). As Figures 4 and 5 show this is primarily due to the high discomfort level associated with the left or noncontrol using foot, leg, and knee.

This finding is supported by the fact that seventy-eight percent of the male and female foot control users from both Plants A and B (N=38) indicated on interview that control use causes asymmetrical or unbalanced weight distribution. Interestingly, the eight individuals that indicated balanced weight distribution had consistently lower pain scores and frequency of complaints across all six lower extremity categories.

Trunk discomfort was significantly greater for the Plant A static standing population (PVA Static Stand) than the corresponding Plant A modular population. Hunched postures were often used by employees during back pocket and belt loop machine operations. This is due largely to severe spacial incompatibilities that exist between worker anthropometry and point of operation location. There was also comparably greater manual materials handling at the static standing workstations. Modular workers from Plants A and B were more like their Phase I counterparts from an upper extremity discomfort perspective. The greater upper extremity discomfort scores reported by the static standing population might also be associated with the greater level of manual materials handling required by the tasks.

The Phase I standing (PI Standing) respondents reported significantly lower trunk and lower extremity discomfort levels and frequencies than the other subject populations. One explanation is that many of the jobs from Phase I (e.g., slide and stop, trim, and hook and eye) had a larger dynamic component from a lower extremity standpoint, did not use foot controls, and required less forceful hand manipulations. The greater average age of the Phase I workforce could also influence this result since the older workers reported fewer discomfort complaints.

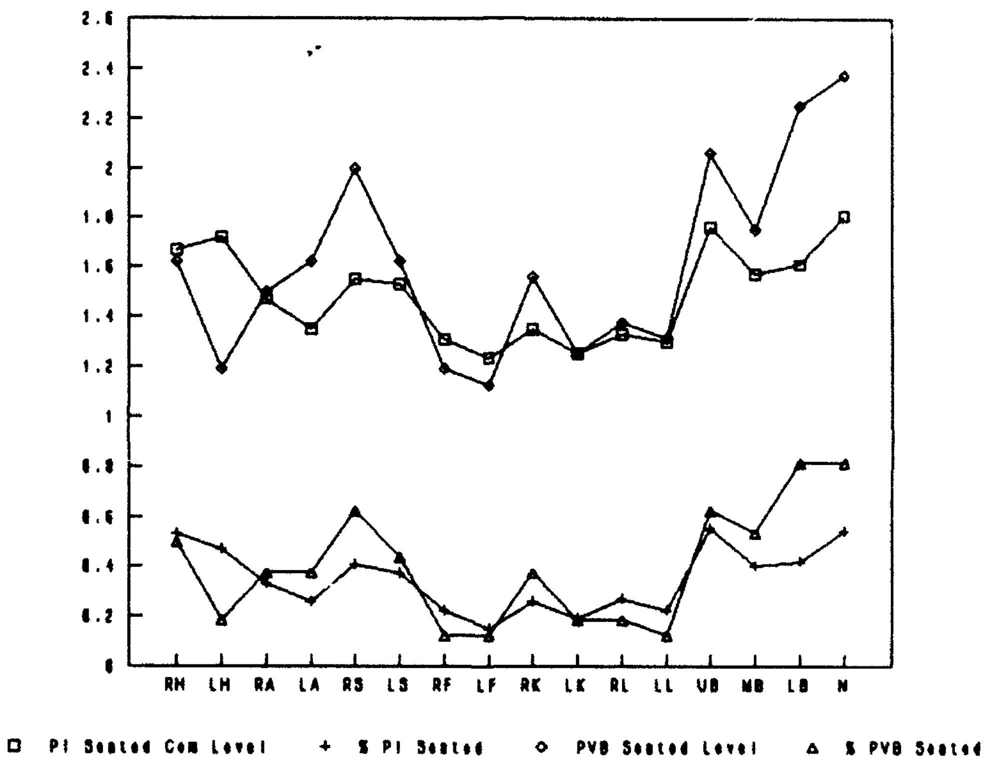

Figure 3. Phase I and Phase V Plant B seated female comfort comparison.

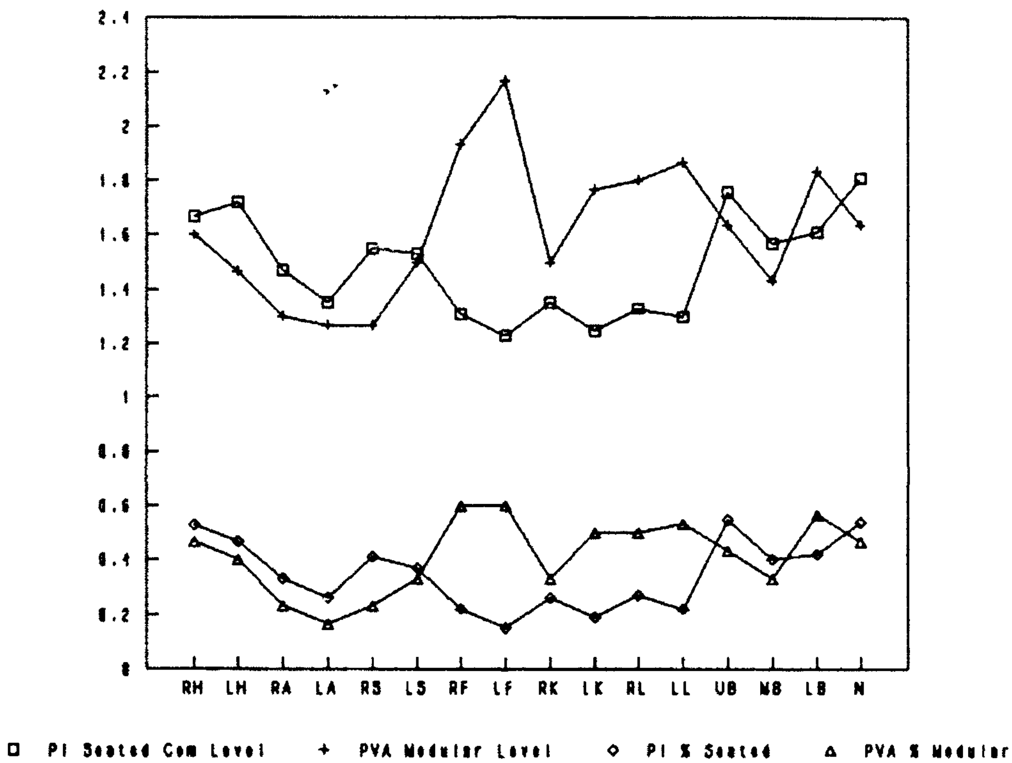

Figure 4. Phase I seated and Phase V Plant A modular standing female body part discomfort comparison.

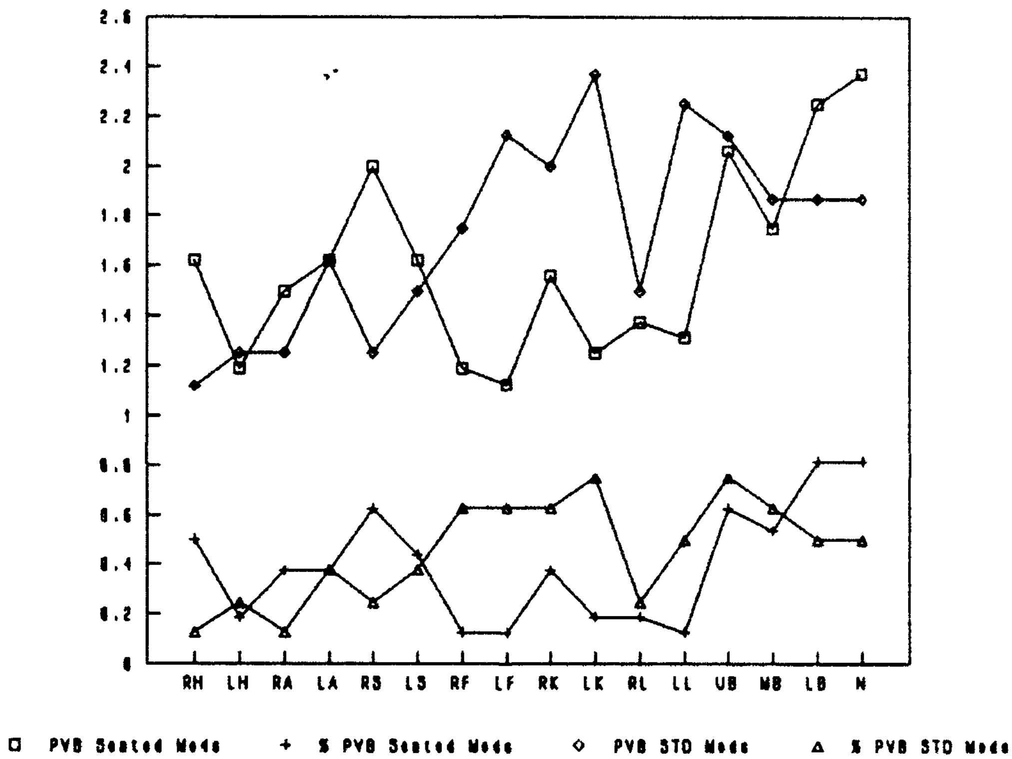

Figure 5. Plant B seated female and standing modular male comparison.

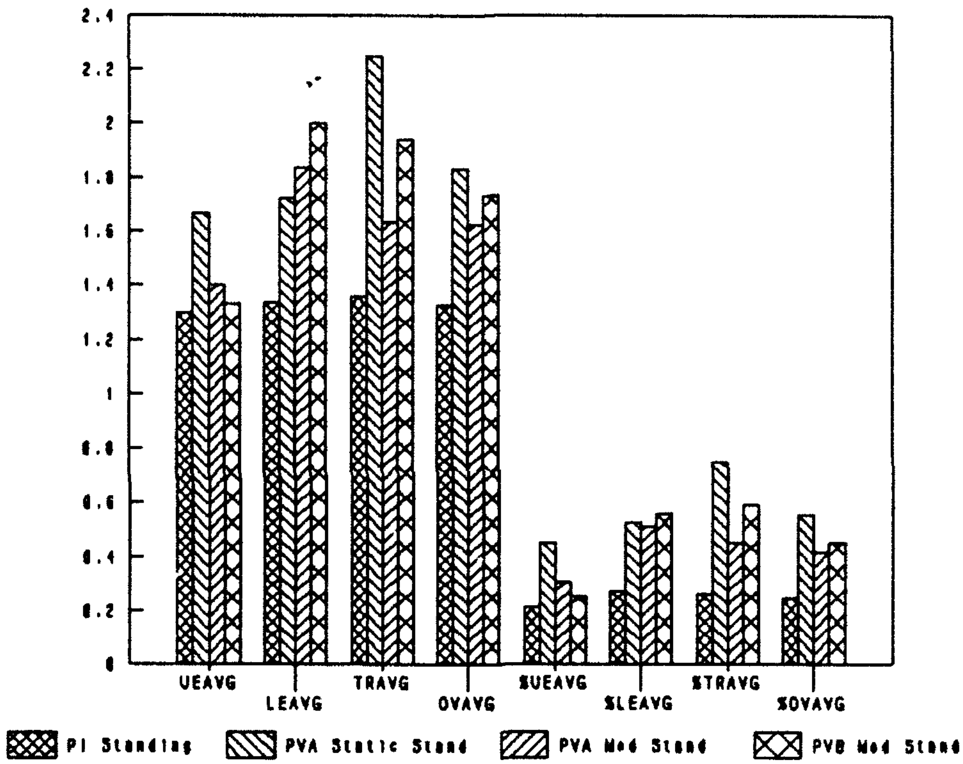

Figure 6. A comparison of Phase I and Phase V standing populations.

Medical Complaints
No major differences exist between Phase I and Phase V study populations concerning medical complaints reported on questionnaire. Twenty-eight percent of the Phase V female study population reported "pain and numbness in the hands at night", a symptom of Carpal Tunnel Syndrome (CTS). Approximately twenty-eight percent of the respondents (only operators at two of three plants were asked this question) in Phase I also reported this symptom.

The Phase V study population data shows large inter- and intra-plant differences in the occurrence of this single symptom complaint. Forty percent of the Plant A female respondents reported this symptom compared to only 8 percent of the female respondents from the Plant B study population. An interesting finding at Plant B was that three of the eight male modular workers interviewed reported the CTS symptom. With this information in mind it is important to note that single symptom complaints are not confirmed cases of CTS and probably over-estimate the actual incidence of CTS in the work place.

There were no reported cases of CTS on the Plant A and B 1990 and 1991 OSHA 200 logs and only one cumulative trauma disorder case (ganglion cyst) in the most recent complete year. The medical problems reported on questionnaire included back strains (5), Carpal Tunnel Syndrome (2), ganglion cyst (2), tendinitis (1). There were also 14 reports of leg cramps among Plant A respondents (eight standing modular and six static standing workers reported this complaint). The discrepancy between OSHA log and questionnaire results is an indicator of recordkeeping problems that continue to persist in industry and are associated with less than adequate training in medical management and surveillance.

Workstation Measures and Worker Anthropometry
The mean work height of selected standing modular workstations in Plant A and B was 40.96 (range=36.50 to 47.75) and 42.75 inches (range=40.00 to 47.00), respectively. The average elbow height among workers from the same locations where the work height measurements were taken was 40.81 inches (range=36.75 to 43.75) for Plant A modular subjects and 42.97 inches (range=41.00 to 45.50) for the Plant B modular subjects. The larger plant B result was due in part to the inclusion of four males in the sample population. With the mean elbow height to work height ratio almost one at both locations it is apparent that management attempted to address the variability in worker anthropometry by making specific work height adjustments.

Job Video Analysis
Video analysis of 21 positions in Plant A trouser module 1 revealed a few differences between this standing module and the traditional jobs analyzed in Phase I. The jobs were, as expected, hand intensive requiring an average of 20 (8 to 42 range) right hand and 25 (9 to 18 range) left hand motions per minute. With cycle times ranging between 12 to 50 seconds (with 71 percent of the jobs in the 20 to 40 second range) the average number of

motions per cycle was 10.0 and 11.4 for the right and left hands, respectively. These values are significantly less than the 29.9 right and 25.6 left hand motions per cycle obtained in the Phase I study.

Like the traditional bundle handling study population, the predominant hand postures were pinching and flat pressing. There was, however, much less non-neutral hand activity (e.g., ulnar and radial deviation and flexion and dorsiflexion of the wrist) associated with the jobs in the Plant A standing module than the corresponding Phase I study population.

The differences in hand activity between the Plant A standing modular and Phase I traditional study groups was not reflected in the comfort data where there were only slight yet insignificant differences in upper extremity discomfort (see Figure 4). With less high risk hand activity, Plant A respondents are in theory at lower risk of developing a work related CTD. This lower exposure was not however associated with a reduction in the prevalence of CTS single symptom reports. Because of the prior experience that many of the respondents had in conventional sewing it may be too early to see the true effect of modular work on employee performance and comfort. Other potential factors impacting the Phase I and V observations noted above include existing differences in task organization, workstation design, productivity, between station movement frequency and microbreaks and inter-analyst recording variability and subject response variability.

Twenty-nine percent of the 21 subjects flexed their torso more than 20 degrees at least once during the machine cycle. Like the Phase I study group, neck flexion greater than 20 degrees was used at least once per cycle by more than sixty percent of the subject population (67 percent). Flexion of the spine is the result of worker and machine geometry incompatibilities and the visual tracking demands of the high precision assembly jobs. This is exemplified by the observation that even with the use of an erect back employees will often flex their neck to gain vision down into the work.

Foot Control Forces

Overall, foot control actuating forces were higher than the treadle actuating forces measured in Phase I. Moreover, like the Phase I foot controls, Phase V control actuating forces showed a high degree of inter-control variability. As noted in the Phase I report (Ortiz, 1989), the problem appears to be associated with control maintenance.

Foot controls were of several varieties within the Plant A trouser manufacturing modular cells. Most were mechanical but some were electrical and pneumatic requiring side to side or downward foot action. Controls were usually positioned by the operator and were anywhere from 0 to 20 degrees from the horizontal (i.e, floor). Of the control systems measured (N = 18), actuating forces ranged from 13 to 174 Newtons (mean = 78 N) with five of the controls outside the recommended range of 15-90 N (Eastman Kodak). Anti-stress mats were in use at most of the modular cell workstations.

Plant B standing Module 13 and 14 foot controls (N=8) were the same design type (mechanical). Control location was flexible to accommodate worker preferences. Like the Plant A controls, the actuating forces ranged widely from 13 N to 120 N (mean=52 N). Only one control was outside the range recommended by Eastman Kodak. Machine actuation and presser foot control required discreet front to back foot movement. Controls were almost level with the anti-stress mats in use at all the standing workstations.

Illumination Considerations
The average illumination level at Plants A and B was 125 and 93 footcandles, respectively. These values are outside the 200 to 500 footcandle illuminance range recommended by Illuminating Engineering Society of North America. As alluded to in a previous section, the visual tracking associated with most sewing tasks requires good visual acuity and higher lighting levels than less demanding tasks. Even with a well designed workstation, in order to compensate for poor lighting, workers will assume a flexed trunk posture to reduce the visual distance to the point of operation.

Employee Attitudes Toward Modular Approach
Of those providing a yes or no response to the question "Do you like the modular team approach?" (N= 40), 82.5 percent responded positively. The most common reasons given for "liking" modular fell into three categories:

Positive Response Category	Number of Comments
1) Moving more/learning more jobs	15
2) Group camaraderie/teamwork/help	13
3) Posture/comfort benefit- back	2

For the 17.5 percent who responded negatively, the common justifications were:

Negative Response Category	Number of Comments
1) Having to support others/wage dependence	3
2) Posture/discomfort problem- feet, legs	2
3) Fighting/discord among group members	1

The majority of workers preferred collaboration on work assignments and the opportunity to move within the plant and learn additional positions. This is consistent with job enlargement concepts which call for increased physical and mental diversity in work design. A corroborating result may be found in the "more or less discomfort with modular" inquiry in which 57 percent indicated an improvement in discomfort versus 16 percent who indicated worsening discomfort.

Increased skills acquisition might also be viewed positively by the workers in terms of increasing their potential for future employment. Also, group dynamics may have reduced performance stress for the workers who felt that intra-group support and assistance were advantages. However, collaboration and shared responsibility have varying appeal among the workforce. A portion of the population found the group setting confining and perhaps unpleasant. The comment distribution also suggests that postural discomfort can be a problem with either system.

Compensation System Preference

With all female operators (N=67) responding, the individual incentive pay scale was favored (49 percent of the respondents preferred) over the group incentive scale (preferred by 30 percent of the respondents) with hourly being the least preferred (21 percent). This indicates that while experiencing benefits from modular, the workers still have a strong identity with their own ability to produce and meet financial needs. Many workers cited "up to you" and "others don't cooperate, don't work as hard" as reasons why they preferred individual incentive. The individual incentive system has an internal locus of control for earnings. In the group situation the locus is more external (a function of the influence of the individual on team performance). There is a loss of control. The emphasis on individual incentives could also be a sign of frustration that group earnings are limited by the weakest performers.

A familiarity factor for the group incentive method may exist. If the respondents are broken down into those on modular jobs (with group incentive exposure) and those on traditional jobs (with no or very limited group incentive exposure) major differences are evident. Those with group incentive experience exhibit greater acceptance, while those without such experience show no interest in group incentive. Exposure to the group incentive approach and the modular team environment may have shifted attitudes in the modular workforce.

Management Attitudes Toward Modular Approach

The manager interviewed at the "unsuccessful" third plant cited the existence of the group dynamic problems described above as important in the decision to return to the traditional bundle handling system. In particular, internal conflict resulting in defensive behavior, lack of cooperation, even fist fights, was reported as a critical problem association with modular cells and the team approach. Other factors reported as contributing to the failure of the modular approach included a reduction in productivity and worker morale; the increased impact of equipment down time and lack of redundancy; wage system problems (incentive to hourly); and inadequate or cramped work space (job to worker ratio was 45 to 27). The failure of the system was most likely due to multiple factor interaction and not just a single factor or event.

These problems arose even though there was much greater worker autonomy and involvement in the operation decision-making process than the traditional system. The absence of a formal employee training program to facilitate the transition from conventional to modular was a likely contributing factor in the unsuccessful conversion attempt. Interestingly the conversion and start-up process did not present a problem and other locations within this corporation are having reasonable success with modular manufacturing.

A summary of Plant A and B management responses concerning modular manufacturing is provided below. Obviously, management from both plants are satisfied with the overall performance of the modular cells within their respective facilities.

<u>POSITIVE RESPONSES</u>
Improved quality
Fewer hand pain complaints
Reduced work in progress and through-put time
Improved morale
Greater flexibility
Turn-over and absenteeism improvement
Reduced torso twisting

<u>NEGATIVE RESPONSES</u>
Reduced productivity
Interpersonal conflict
Absenteeism creates problem from lack of redundancy
Lack of equipment redundancy
Foot control problems
Slower through-put

DISCUSSION AND RECOMMENDATIONS

Based on our results, there are no major differences between the Phase V modular and Phase I traditional progressive bundle system data from an ergonomic perspective that would argue against standup or seated modular work. Moreover, the only significant difference between seated progressive bundle system and standing modular system workers in trouser manufacturing was the greater lower extremity discomfort reported by the standing modular workers. The benefits expected from a job that permits frequent movement (e.g., improved lower extremity comfort) was possibly negated by the use of machine foot controls.

Clearly, the postural and workstation design and illumination issues addressed in Phase I have direct application to modular manufacturing environments as well (Ortiz, 1989). To minimize postural stress, workstation flexibility is needed to accommodate the diverse and rapidly moving worker population within modular work cells. In particular, with workers trained to operate more than one machine there is a need for workstations to be easily adjustable in the vertical plane to locate the work within the operator's normal reach envelope (e.g., elbows down close to the body, 90 degree flexor angle, and frequent forward reaches limited to 16 inches). Presently, there are few commercially available machine tables that meet this need and those available are generally expensive. Moreover, the use of a sit-stand workstation for jobs within modular cells should be considered as long as the worker's upper body configuration does not change when they move from sit to stand.

One hypothesis associated with an enlarged job that permits frequent between station movement is the transfer between different tasks might provide a regular microbreak from hand intensive work thereby reducing employee exposure to cumulative trauma disorders. Such a benefit was not revealed in this study, however. With employees from both Plants with one year or less experience in the modular work environment it may be too early to detect or separate from past exposure to conventional apparel manufacturing any medical contributions from this newly introduced manufacturing approach. In order to maximize any medical or ergonomic benefit from job enlargement operators would have to move between jobs that have significantly different force, repetition, and body part requirements.

There was substantial variability in hand activity associated with the standing modular jobs in Plant A module 1, but the organization of the jobs did not allow workers to always rotate between two or more disparate operations. Consequently, special consideration must be given to the configuration and organization of the jobs in the cell to allow the worker to rotate between significantly different jobs. Moreover, research is needed to predict or determine the optimal job to worker and work area to worker ratios to promote human performance and minimize the potential problems associated with working in groups.

The lower extremity discomfort result with the standing modules was predictable. Machine controls that require the use of the operator's foot may be associated with considerable discomfort and, therefore, may not be optimal for standing work. Further investigation is needed to identify new and existing control devices that might be more appropriate for standing modular work (including "new design" foot control systems). Voice control and body actuated machine control systems (e.g., operator leans into control bar) are under development or are commercially available. Even so, the effect of any control system on human performance and comfort should be carefully assessed before it is placed or considered for wide use in the apparel industry.

With the expected continued use of existing foot control systems (until a better system can be developed) the following guidelines should be considered: (1) controls should be placed on a preventive maintenance schedule to keep actuating forces to a minimum; (2) they should be flexible (e.g., easily positioned in place) so operators can assume erect and stable postures (e.g., work with elbows down close to body) during machine operations and possibly alternate feet; (3) foot guards or covers should be used to prevent accidental machine actuation; and (4) foot controls should be as level as possible with the floor or walking surface. Although we did not attempt to measure the benefit from the use of anti-stress mats in this study, they are recommended in standing work to more evenly distribute the worker's weight on the feet and reduce lower extremity discomfort. Such mats should be tapered around the edges and sharply contrast with the walking surface to reduce the trip hazard to employees. With the relatively frequent between station movement in modular cells it may be practical to carpet the entire work cell walking area with a compressible material rather than place small mats at each workstation.

Many of the workers in modular tasks seem to have a positive attitude about the work system. Even with greater discomfort to the lower extremities, a majority of the employees with experience in both seated traditional and standing modular work prefer the latter over the former. To some extent, worker attitudes regarding compensation are changing as their familiarity with the new approach increases. However, there is still some difficulty to be faced in integrating modular approach with the existing work force.

Modular entails a move from an individually controlled task setting where interaction is limited and even discouraged to a system where individual control is substantially weakened and personal interaction is crucial. This transition may be difficult for some employees. This indicates the need for gradual introduction of the modular concept and extensive training support to enhance worker acceptance and minimize impact on the worker. Careful attention should be given to group composition/interaction and procedures put in place to resolve conflicts within the group. A key factor is refocusing worker attitudes. Efforts should connect individual goals with group goals such as enhancing organizational competitiveness and its relationship to personal employment security. Other major factors to emphasize are those the workers themselves have indicated in this study. The security and interaction of the work team may be attractive to some workers. For more independent workers, the benefit of learning additional marketable skills should be emphasized. Management can reinforce cooperation and employee support for the team process by exhibiting a participatory spirit.

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APPENDIX A
Comfort and Medical Questionnaire

GEORGIA TECH ERGONOMICS SURVEY

Date ____________________

Plant ____________________

Interviewer ________________

Module/Line ______________

General

The following information will be used for describing the participants in terms of age, job, sex, and experience, and also in summarizing the results by those categories.

Job Title ____

Job is performed while: seated standing both. Age ___ Sex M F

How long employed at this plant ____________/on this job _____

Extent of previous employment in similar job (approx. years) _____

How long on modular job? (approx) _______ years ________ months

Position in module? ______________________________________

Major hobbies and sports activities (estimate average number hrs/week):

____

____

____

Medical Background

During the past twelve months, have you been treated **by a doctor** for any problem related to the muscles, tendons, or joints of your body? Examples of these problems are back strain, arthritis, tendonitis, herniated disc, and carpal tunnel syndrome. Yes No

If yes -- indicate diagnosis

____

____

Physical Discomfort

The following questions are about physical discomforts you may experience while working, or that you believe are work-related. Use the following scale to indicate how often you have experienced pain or stiffness in each body part within the past 6 months (or since starting to work here, if less than 6 months). (circle one)

	Never	Sometimes	Frequently	Constantly
Right hand/wrist	1	2	3	4
Left hand/wrist	1	2	3	4
Right arm (incl. elbow)	1	2	3	4
Left arm	1	2	3	4
Right shoulder	1	2	3	4
Left shoulder	1	2	3	4
Right foot/ankle	1	2	3	4
Left foot/ankle	1	2	3	4
Right knee	1	2	3	4
Left knee	1	2	3	4
Right leg (other than knee)	1	2	3	4
Left leg	1	2	3	4
Upper back	1	2	3	4
Middle back	1	2	3	4
Lower back	1	2	3	4
Neck	1	2	3	4

Do you ever have numbness in any of your joints at night? Yes No
(If Yes, elaborate below)

____

Do you ever have a problem with your feet or legs going to sleep while you are working?
Yes No

List other physical discomforts you have experienced within the past 6 months that you believe are work related (for example, eyestrain, leg cramps, etc.):

____

Before joining the modular group, did you work in a conventional sewing line?
yes no

If yes, do you experience more or less discomfort since switching to the modular group?
more less same

Do you experience discomfort in different areas of your body since switching to modular?

____

Chair Design and Use

The following questions are about the chair you use while working. Skip these questions if your job is performed entirely while standing.

Do you do all of your work or part of your work while seated? All Part

If you do part of your work seated, what percentage of your time is spent seated?

Do you have your own chair or do you share it with others? Own Chair Share

Does your chair have the following features:

adjustable seat height	Yes	No
adjustable backrest	Yes	No
swivel side to side	Yes	No
tilt front to back	Yes	No
armrests	Yes	No
wheels or rollers	Yes	No

(If seat height or backrest are adjustable, answer the following.)

Has anyone shown you how to adjust your chair? Yes No

Did anyone adjust the chair so it would be right for you? Yes No

Can you adjust the chair yourself? Yes No

Have you used cushions in your chair to:

Raise your seating height? Yes No

Be more comfortable? Yes No

Do you use a footrest? Yes No

Do you have enough legroom under your work table so that your knees and legs are comfortable? Yes No

Standing Workstation

The following questions are about your standing workstation. Skip this section if your work is done entirely while sitting.

Is the top of your workstation adjustable up and down by yourself? By the engineers?

____

If it is adjustable by yourself, how frequently do you adjust it?

____

Do you use foot pedals to control your machines? yes no

____

Does the foot pedal allow you to keep your weight evenly on both your feet?

yes no

With which foot do you normally use the foot pedal? left right both

Describe the foot pedal.

____

____

Do you use knee switches to control your machines? yes no

With which knee do you normally use the knee switch? left right both

Do you have any kind of stool or rail to lean against while working? yes no
If yes, describe it.

____

Workstation Design and Use

The following questions are about your workstations. What positions do you usually work in the module?

1.____________________ 2.____________________

3.____________________ 4.____________________

Rank the positions according to how much time you spend in each.

1.________________ 2.____________

3.________________ 4.____________

How proficient are you at each of these positions (below average, average, above average)?

1.__________ 2.__________

3.__________ 4.__________

Does your job require you to:

- stretch either arm fully (or almost so) to reach things? Yes No
- bend, lean, or stoop to reach things? Yes No
- raise either arm above your shoulder? Yes No
- lifting a bundle (or other heavy item) with your arms? Yes No
- carry heavy loads from one place to another? Yes No
- push or pull a cart or horse? Yes No

If you answered yes to any of these, describe what you have to do.

____

____

Do you have enough space at your workstations for:

- the stacks of pieces you work on? Yes No
- other work items (supplies, clippers or scissors, etc) Yes No
- personal items you have at work (purse, coffee cup, etc) Yes No

---

Do you ever have a problem with:

- work table height (too high or too low)? Yes No
- height/placement of your pedal, treadle, or knee switch? Yes No
- having to lean forward to see what you're working on? Yes No

List any other workstation problem: ____________________

Wage preference

Do you prefer hourly, group-incentive, or individual incentive pay scales?

hourly group incentive individual incentive

Why?

____

____

Training

The following questions are about training you may have received at this plant. Remember that the questions are about training at this plant -- not other places you may have worked.

When you first started to work here, how long was your training period?

____

Have you received additional job training (such as for a different job) since then? (Indicate what type and how long)

____

____

In any of your job training at this plant, have you been given charts, work diagrams, or other written job descriptions to study and/or keep for yourself? Yes No (If yes -- indicate what)

___

Have you ever been shown a videotape of someone performing your job or a very similar job? Yes No

What kind of training did you receive to prepare you to work in the modular group?

___

___

Have you ever been trained or instructed about the importance of correct posture in making you comfortable while working? Yes No

Have you ever received safety training to show you how to operate your machine to reduce risk of accidents and injuries? Yes No

List any other special training you have received at this plant:

___

___

General Comments

Is there any part of your job that you think is a lot harder than other parts? Explain.

___

___

___

Do you like the modular team approach? Yes No

Why?___

___

Now tell us more about any problems you mentioned in the earlier questions, and tell us anything else you believe would help make your job better for you.

___

___