Final Performance Report

Ergonomic Study of Fire Service Musculoskeletal Injuries

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TABLE OF CONTENTS

SIGNIFICANT FINDINGS

The significant findings of this study are discussed in terms of the three specific aims of the study. The first specific aim was to identify frequently-performed physically strenuous job tasks of firefighter/paramedics (FF/Ps) engaged in emergency medical service (EMS) tasks. Through a process of 29 qualitative interviews and a survey of almost 400 FF/Ps, this study validated a list of the most frequent and strenuous EMS tasks performed by FF/Ps. The 11 EMS tasks were ranked based on a composite score of survey ratings of frequency and strenuousness.

The second aim was to conduct an ergonomic task analysis. This study demonstrated the feasibility of producing reliable and valid data by simulating the tasks carried out on typical EMS runs. Work task data were captured on videotape and using Lumbar Motion Monitors (LMMs). These data allowed different postures representing separate components of the EMS tasks to be quantified. In addition, the forces applied by FF/Ps as they completed the simulated EMS tasks were quantified. Strength limitations were identified and spine compression forces were calculated using the University of Michigan Three Dimensional Static Strength Prediction Model (3DSSPM). Finally, the relative risks for Low Back Disorder (LBD) were determined using the Trunk Motion Logistic Regression Model (TMLRM) developed at Ohio State University.

The third aim was to hypothesize ways to reduce musculoskeletal stresses in the identified tasks. Based on the ergonomic task analysis, the following modifications are hypothesized to be feasible methods for reducing the risk of musculoskeletal injuries among FF/Ps.

- A waist-supported, hands-free system for backboard transport.
- An articulated backboard with a locking mechanism.
- An adjustable-length backboard with a locking mechanism.
- A low-friction bed-to-stretcher interface.
- A tri-wheel stairchair.

USEFULNESS OF FINDINGS

In terms of the first specific aim, the list of frequently-performed strenuous job tasks derived from the interview and survey phases of the study was used to select tasks for the simulation phase of the study. In addition, the reliable and valid survey questionnaire that was developed for use in this study can be used to investigate other similar fire service populations.

In terms of the second specific aim, the ergonomic task analysis process demonstrated a feasible way to conduct ergonomic research on tasks that cannot be systematically observed during actual operations because of practical, legal, or ethical constraints. The ergonomic task analysis identified the postures that put firefighter/paramedics (FF/Ps) at risk for musculoskeletal injury. The analysis also identified the tasks during which musculoskeletal overexertion injuries, or disc-related back injuries, are likely to occur. The simulations developed for this study could serve as the basis for task-specific training and physical conditioning programs. In fact, the Principal Investigator used the task analysis data from this study to help develop a physical-fitness intervention program for FF/Ps. That intervention is part of a current, NIH-funded study.

In terms of the third specific aim, the ways to reduce musculoskeletal injury that were hypothesized in the final phase of this study can be used to guide future research efforts. Furthermore, the hypothesized ways to reduce injury suggest design changes in EMS work methods and equipment that should be investigated.

The significant findings from this study, and the usefulness of those findings, are summarized in Table 1.

ABSTRACT

Ergonomic Study of Fire Service Musculoskeletal Injuries

Musculoskeletal injuries account for almost half of all injuries among the one million firefighters in this country. These injuries result in excessive absenteeism, costly medical claims, and disability. The handful of studies conducted on musculoskeletal injuries in the fire service have examined job tasks in relation to the physical requirements (e.g., aerobic capacity, flexibility, and strength) needed to perform fire suppression tasks. In actuality, today's firefighter is increasingly cross-trained as both a firefighter and a paramedic or an emergency medical technician. (This study refers to such cross-trained personnel as firefighter/paramedics [FF/Ps].) Such cross-training is effective, because these days a fire department can easily find that over 60% of its runs are for emergency medical services rather than for fire suppression. There is a need to examine the FF/P job from an ergonomic perspective and describe the biomechanical stresses encountered in the job. These stresses include handling heavy people (victims) and equipment, through lifting, twisting, stretching, and reaching.

The objective of the present study was to describe the frequently-performed strenuous emergency medical service (EMS) tasks that place the FF/P at risk for musculoskeletal injury and to hypothesize ways to reduce this risk. The study population was 542 FF/Ps from 14 suburban fire departments. The study was conducted in four phases. The content domain of frequently-performed physically strenuous tasks was identified in the first two phases. In the first phase, an initial list of tasks was identified through structured interviews with a sample of 29 FF/Ps. (The interview was pilot-tested with 5 FF/Ps.) In the second phase, a list of the 11 most frequent and strenuous tasks identified in the interviews was validated through a mail survey returned by 374 (74%) of the FF/Ps. (The survey was pilot-tested with 24 FF/Ps.) In the third phase of the study, the 5 most frequently performed strenuous tasks identified in the survey (plus one additional task) were simulated and the working postures and the forces applied by the workers were recorded and described. Each task was simulated by 10 teams of FF/Ps who volunteered to participate. Video data were used to determine gross postures and movement ranges. More detailed kinematic data were obtained for the torso using the Lumbar Motion Monitor (LMM). In the last phase of the study, the biomechanical stresses were analyzed and the relative risk of low back disorder (LBD) was quantified. The end product of this study was the generation of hypothesized ways to reduce the risk of musculoskeletal injury associated with frequently-performed, strenuous EMS tasks. Finally, a subsequent study is proposed. The goal of the subsequent study will be to test the ideas for improving the design of EMS work methods and equipment that were generated in the final phase of the present study.

BODY OF REPORT

BACKGROUND AND SIGNIFICANCE

The fire service is one of the most hazardous industries in this country. Its work-related injury and illness rates exceed those for most other industries (International Association of Fire Fighters, 1996; Karter & LeBlanc,1996; Reichelt & Conrad, 1995). For example, the incidence of work-related injury in the fire service in 1995 is reported to have been 4.5 times that for private industry, with 37.6% of firefighters reporting injuries (International Association of Fire Fighters, 1996). In 1995, the National Fire Protection Association estimated that there were 94,500 fire service injuries that required medical treatment or resulted in at least one day of restricted activity (Karter & LeBlanc, 1996). In 1995, there were 9597 lost-work hours per 100 workers due to firefighter injuries (International Association of Fire Fighters, 1997).

Musculoskeletal injuries account for about half of all injuries among the one million firefighters in this country (International Association of Fire Fighters, 1996; Karter & LeBlanc, 1996). Musculoskeletal injuries result in lost worktime, costly medical claims, and even permanent disabilities and premature retirements. These injuries are primarily sprains, strains, and muscular pain, which occur most frequently to the back (Matticks, Westwater, Himel, Morgan, & Edlich, 1992). It is increasingly common for firefighters to be cross-trained both as firefighters and as paramedics or emergency medical technicians (EMTs). (This study refers to such cross-trained personnel as firefighter/paramedics [FF/Ps].) Accordingly, the above-noted statistics reflect injuries and illnesses that result from engagement in fire suppression, rescue, and emergency medical service (EMS) operations. Studies of non-firefighter paramedics and EMTs report similar statistics for musculoskeletal injuries (Hogya & Ellis, 1990; Stilwell & Stilwell, 1984).

The ranking of musculoskeletal injuries as the primary and most costly injury in the fire service parallels the case for U.S. workers in general (Andersson, Pope, Frymoyer, & Snook, 1991; Bigos, Battie, Spengler, Fisher, Fordyce, Hansson, Nachemson, & Zeh, 1992). For U.S. adults of working age (18-64 years old), the estimated cost of musculoskeletal conditions was $79 billion dollars in 1988 alone (Praemer, Furner, & Rice, 1992).

Research on Musculoskeletal Injuries in the Fire Service

There is little research on the full range of causal factors of work-related musculoskeletal injuries in the fire service. Fire service musculoskeletal injury research has focused on firefighters' engagement in physical fitness activities, particularly on flexibility activities. A large prospective study of Los Angeles County firefighters related pre-employment physical measurements to subsequent work-related back injuries (Sullivan & Yuen, 1986). This study concluded that trunk flexibility was the strongest protective factor against the occurrence of work-related back injuries. A flexibility intervention study by Hilyer, Brown, Sirles, and Peoples

(1990) concluded that improved flexibility among firefighters participating in an intervention program was associated with fewer joint injuries, less absenteeism, and lower worker compensation costs. That study suggested that mandatory flexibility training may yield positive outcomes in the short term. Work by Cady and colleagues also supports the association between physical fitness in firefighters and fewer musculoskeletal injuries (Cady, Bischoff, O'Connell, Thomas & Allan, 1979; Cady, Thomas, & Karwasky, 1985).

Doolittle and Kaiyala (1986) concluded that there was an inverse association between strength and musculoskeletal injury. This was the only firefighter study reviewed where an attempt was made to control for risk of exposure to musculoskeletal injury. In that study of multiple fire stations, exposure was defined as the number of hours spent on the fire scene per fire station. While this is an admittedly gross aggregate measure of exposure, it does represent acknowledgment that exposure needs to be quantified in studies examining associations between fitness and injury rate.

Fire service research:
Job task analyses to identify physical requirements for job

A few studies have examined firefighting tasks in relation to the physical requirements needed to perform the job (Davis, Dotson, & Santa Maria, 1982; Doolittle, 1979, 1989; Lemon & Hermiston, 1977; Romet & Frim, 1987). In their first study, Dotson, Santa Maria, Davis, and Swartz (1977) quantified the physiological and physical requirements of the structural firefighter. For this seminal study of 100 career firefighters, the Fire Training Offices of the Metropolitan Council of Governments in Washington, DC nominated a representative list of frequent and critical firefighting tasks. Five tasks from the nominated list were selected for use in the study. Performance of the five tasks was timed. Correlation analysis identified key variables relating physical performance and the simulated firefighting tasks. The two primary factors associated with high performance in the simulated tasks were high aerobic energy involvement and resistance to fatigue. The Dotson et al. (1977) study concluded that high muscular strength and endurance as well as near-maximal aerobic capacity were required to successfully complete the simulated tasks. (An electronic search of nine databases and a manual literature search in preparation for this report showed no additional publications on the topic).

Since the time of the Dotson et al. (1977) study, the five fire suppression tasks often used as a basis for job task analysis have remained essentially the same (stair/ladder climb, hose advance, simulated forcible entry/chopping, hoist evolution/standpipe hose load pull, and simulated victim rescue - dummy drag) (Davis et al., 1982). These tasks simulate the metabolic demands imposed on a firefighter during actual fire suppression work. The physical requirements identified by Davis et al. (1982) concerned primarily aerobic capacity, and to a lesser extent flexibility and strength. The purpose of the job task analysis work described was to identify physical requirements for the job, not to examine biomechanical risk factors for musculoskeletal injury.

The Need:
Task Analysis to Quantify Biomechanical Stressors Related to Musculoskeletal Injury Among FF/Ps

The few studies noted above examined firefighting tasks in relation to the physical requirements needed to perform job tasks. Their emphasis was on fire suppression tasks, not EMS tasks. Not only have firefighters always performed both fire suppression and EMS tasks, but today's firefighter is increasingly cross-trained both as a firefighter and as a paramedic or EMT. Such cross-training is effective, because today over 60% of fire department alarms are for emergency medical services rather than for fire suppression (International Association of Fire Fighters, 1996). Only one study was found that quantified the biomechanical stressors inherent in the EMS part of the job. It was an unpublished report, and it provided only sketchy details of the process (Doolittle, 1989).

The significance of the present study is summarized by the following points:

1. Musculoskeletal injury is the most common type of injury among this nation's one million firefighters.

2. In the nation's fire departments, FF/Ps are performing EMS tasks more frequently than they are performing fire suppression tasks. Yet, the biomechanical parameters involved in the performance of EMS tasks have not been quantified in a systematic way.

3. The present study used an ergonomic approach to identify the EMS tasks that expose FF/Ps to biomechanical stressors. The present study also quantified the biomechanical parameters of those tasks.

4. This study lays the groundwork for subsequent simulation studies by hypothesizing changes in work methods and equipment that should reduce the risk of musculoskeletal injury while performing EMS tasks.

5. The information obtained from the present study (and a proposed follow-up laboratory study) will form the basis for a comprehensive intervention study to reduce musculoskeletal injury among FF/Ps performing EMS tasks. The comprehensive intervention study will seek to alter manipulable factors located in the fire service worker, fire department policies and procedures, EMS work methods, and fire service equipment.

CONCEPTUAL FRAMEWORK

NIOSH's document on musculoskeletal injuries suggests that preventive strategies should take into account (a) workplace hazards, such as heavy lifting or repetitive, forceful manual twisting; as well as (b) behavioral or lifestyle factors, such as physical fitness activities (Department of Health and Human Services, 1986). The combination of worksite hazard control and worksite health promotion can clearly enhance the level of workers' health both on and off the job. Unfortunately, there is little research that comprehensively integrates worksite hazard control and health

promotion. Despite the contrasting nature of these two types of approaches, they are in fact complementary and can be synergistic (Cohen, 1989).

Taken together, both NIOSH's directive and the available research point to the need for a conceptual framework that integrates hazard control and health promotion approaches. Such an integration considers both personal factors (such as physical fitness) and workplace factors (such as biomechanical stressors) as contributors to the occurrence of musculoskeletal injuries.

The conceptual model that guided this study posits that desired health outcomes, such as reduced musculoskeletal injury, are determined by both individual factors and by factors beyond the individual. In this case, factors beyond the individual include the workplace and the external environment in which the emergency medical services are rendered (Conrad, Balch, Reichelt, Muran, & Oh, 1994). The model maintains that the factors are interrelated and that prevention efforts must be directed at both the individual and the workplace. In this study, the major workplace factors to be examined were biomechanical stressors created by the performance of FF/P tasks and the interaction with fire service equipment. The person factors were captured in the form of anthropometric measures. Situational factors at the scene of the emergency were also considered.

The conceptual model was a product of our preliminary focus group study (Conrad et al., 1994). The purpose of the focus group study was twofold: (a) to elicit firefighter/paramedics' perceptions, attitudes, and feelings about the personal, workplace, and uncontrollable situational factors that contribute to musculoskeletal injuries, and (b) to develop a collaborative relationship between university researchers and the fire service. It was felt that obtaining input and cooperation from fire service groups in the early phases of the research would help secure their commitment and would help insure that any preventive approaches developed would address the causes of the problem in a way that the fire service would see as valid and acceptable.

The population for the focus group study consisted of the same 14 fire departments that participated in the present study. In all, 39 individuals participated in the focus group study. Regardless of whether an individual (a) was a fire chief or one of the non-management personnel, (b) exercised or not, or (c) had incurred a compensated lost-time injury or not, there was agreement on a number of issues. Getting injured as a firefighter is inevitable, even though the injury may not result in time lost from the job. The person, workplace, and uncontrollable situational factors identified in the focus group study that have relevance for the present study include: (a) person factors such as physical fitness, anthropometric dimensions, history of musculoskeletal injury, age, gender, and experience; (b) workplace factors such as job tasks (e.g., lifting, bending, twisting), equipment, and the tradition within a given fire department about how to perform selected EMS job tasks; and (c) uncontrollable situational factors such as the EMS working situation (e.g., confined spaces or steep or winding staircases).

SPECIFIC AIMS

The objectives of the present study were to describe the Emergency Medical Service (EMS) tasks that place firefighter/paramedics (FF/Ps) at risk of musculoskeletal injury and to hypothesize ways to reduce the injury potential of those tasks. The ultimate goal of our long-term research program is the development of a series of comprehensive preventive interventions that integrate both health promotion and hazard control approaches. Quantifying the biomechanical parameters of FF/P tasks and understanding the variability that exists within the tasks is a prerequisite to the development of a sound, integrated prevention approach to reducing the severity and frequency of musculoskeletal injuries. The specific aims of the study were the following:

1. Identify (a) the physically strenuous EMS tasks most frequently performed by firefighter/paramedics, and (b) the contexts in which those tasks occur.

2. Quantify via task analyses the trunk motion parameters (range of motion, velocity, and acceleration) and the workplace parameters (work heights, reach distances, applied forces, and subtask frequencies) that are encountered in the most frequently performed, physically strenuous EMS tasks

3. Hypothesize ways to reduce musculoskeletal stressors in the identified EMS tasks. These hypothesized modifications would encompass the redesign of equipment and of methods of task accomplishment. The hypothesized modifications should be such that their validity can be tested in subsequent laboratory studies.

METHOD AND RESULTS

There were four distinct phases to this study, with each phase building upon the previous one. To facilitate reader understanding, each phase is reviewed separately, in turn. A separate Method Section and a separate Results Section are provided for each phase.

Phase 1 -- Task Identification

Method: Structured Interviews

Approach

In order to accurately identify the most frequently performed, physically strenuous tasks carried out during emergency medical service (EMS) activities, we wanted to interview the personnel who actually carry out those EMS tasks.

Subjects

We asked the fire chiefs of 14 participating suburban fire departments to identify the categories of line-duty personnel that regularly participated in the physical work of extricating or moving victims during EMS runs. To create the population list

from which to draw a sample of such personnel for the mailed survey, we asked the fire departments to provide us with the names of all personnel in those job categories. [We learned that personnel with a variety of job titles carry out EMS tasks and that, in some fire departments, personnel rotate in and out of the positions responsible for EMS tasks. Therefore, we included all relevant job titles and position rankings as we recruited participants for both the interview and survey phases of the study.] Although the population of firefighter/paramedics (FF/Ps) employed by the participating fire departments is primarily White male, we asked fire departments to indicate the gender and racial/ethnic category for each person they listed so that we could include female and minority FF/Ps to the extent possible. The 29 interviews conducted included I Black male, I Asian male, and 3 White females. The remaining 24 participants were White males.

The 29 interviews were conducted with personnel from 8 of the 14 participating fire departments. The 8 fire departments included varied in terms of the age, design, and density of the residential, commercial, and industrial buildings in their service territory. The fire departments also varied in size, economic resources, and staffing schemes (e.g., union versus non-union; full-time versus paid-on-call). We concluded the Interviewing Phase after the 29th interview, because we had achieved redundancy in the information being generated by the interviewees. Participation in the interviews was voluntary. Most of the interviewees were eager to describe and demonstrate the nature of their EMS tasks and explain what made them physically challenging. Most of the interviewees reported that they found the interview process to be a rewarding experience.

Procedures

Fire departments were approached one at a time for the purpose of recruiting personnel to be interviewed. A letter was sent to all personnel in the target fire department who had been listed as appropriate for inclusion in the study. The letter indicated the purpose of the study and the nature of the interview process. The letter explained that a researcher would be calling to speak to personnel about voluntary participation. The calls made to recruit personnel for the interviews included a set of screening questions to insure that the personnel interviewed would be those who did frequently perform EMS activities that they considered to be strenuous.

Participants were interviewed one at a time at their firehouse, with interviews lasting up to one hour. The interviews were audio/videotaped for review by the other members of the research team. Videotaping was used to capture detailed task descriptions and demonstrations of postures. These tapes provided the research team with initial information about the types of tasks that might need to be simulated. Thus, it was possible to begin the planning necessary to locate a suitable physical facility and to secure all the necessary equipment for creating the task simulations in which the actual biomechanical stresses would be measured. In order to test and refine the interview format, 5 pilot interviews were conducted with personnel from a fire department that resembled (but was not one of) the 14 fire departments involved in the full study.

Instrument

The following open-ended questions were used to guide the interviews:

- Which EMS/rescue tasks are both strenuous and frequently performed? (Suggested criteria for "strenuous" included subsequent fatigue or soreness.)
- Describe the kinds of runs on which these tasks occur. How often does the fire department make such runs? How often do you participate in them? What are the job titles of personnel that perform these tasks?
- Describe the physical settings in which you perform these tasks.
- What is it about these tasks that makes them physically strenuous?
- What kind of equipment is used in performing these tasks?
- Most of these tasks involve more than one person. What are the different roles that personnel perform while completing these tasks?
- Describe and demonstrate the movements and postures associated with each of the roles involved in performing each of these tasks.
- Out of the physical postures you go through to perform these frequent and strenuous tasks, which are the most strenuous postures?
- What are the sources of strenuousness in performing this particular task (e.g., gross weight lifted versus awkwardness of posture)?
- What is the type of exertion encountered in this particular task (e.g., burst of effort versus sustained effort)?
- What are the key muscles and joints involved in performing this particular task?
- What is the duration of maximal exertion in this particular task?
- Have you experienced any fatigue, soreness, or injury as a result of performing this particular task? If so, name the affected muscles and joints.
- How would you rank the strenuousness of this particular task compared to the other tasks you have described as strenuous?
- Do you have any immediate suggestions for making these tasks less strenuous?

Results of the Structured Interviews

The hand-written notes of the interviewer, the audiotapes, and the videotapes were used by the research team in the analysis. Frequency counts were compiled for the list of tasks mentioned in the interview . A detailed description was written of each of the top 11 tasks mentioned. The description included details of the roles performed in each task. This information was used in the survey phase of the study.

Phase 2 -- Task Confirmation

Method: Quantitative Task Survey

Approach

Based upon the information obtained from the 29 interviews, the researchers drafted a survey questionnaire to obtain data from the population of firefighter/paramedics (FF/Ps) employed by the 14 fire departments. Data was sought about the frequency of performance and the physical strenuousness of the identified emergency medical service (EMS) tasks.

Subjects

The main survey was a census (i.e., a 100% sample) of the population of all FF/Ps in the 14 fire departments who had previously been identified as regularly performing EMS tasks. A packet containing the questionnaire and a postage-paid, pre-addressed envelope for returning the questionnaire directly to the SRL was sent to each of the 518 FF/Ps. (The 24 who had been used in the pilot study were excluded from the main survey.) A total of 374 usable questionnaires were returned for a mailed survey completion rate of 72%. (This is an excellent completion rate.)

Survey Instrument

The draft questionnaire was reviewed by the Questionnaire Review Committee (QRC) of the University of Illinois Survey Research Laboratory (SRL), with whom we contracted to conduct the survey fieldwork. A pilot test was conducted with 24 FF/Ps to evaluate the appropriateness of the instrument and the survey procedures. Of the 24 pilot surveys distributed, 19 were returned, yielding a completion rate of 79%. Because the questionnaire was solidly based upon the interview data, no changes to the EMS task list were required. Based upon the pilot study data and feedback from the QRC, the questionnaire response format was slightly revised and minor changes to the coding procedures were made. The questionnaire was then finalized and printed in an easy-to-use booklet format (see Appendix A).

The questionnaire asked the FF/Ps to rate 11 EMS tasks in terms of frequency of performance and physical strenuousness. The 11 tasks, derived from the interviews, are listed in the survey booklet (Appendix A). For each task, the FF/Ps were asked to provide ratings for each of two separate jobs that were described as being part of the task. These jobs describe how the FF/P is maneuvering the patient or piece of equipment. For example, Task 6 is transporting a patient on a backboard down a straight line of steps while being in the higher position walking forward (Job 1) or being in the lower position walking backward (Job 2). The questionnaire also asked for age category, years of relevant work experience, and whether or not the FF/P was currently experiencing physical pain or had changed work methods because of physical pain.

Procedures

The packets for all the prospective participants at a particular fire department were sent in one bundle by express service to that fire department. To encourage response, the survey cover letter stated that, as a token of thanks to FF/Ps who completed the survey, a drawing would be held to give away three cash prizes (a $ 100 grand prize, a $75 second prize, and a $50 third prize). A letter was also sent to each fire chief urging him to encourage participation among his FF/Ps. Approximately 14 days after the initial mailing, a follow-up postcard was sent to all the FF/Ps and a follow-up letter to each chief. One month after the initial mailing, a second mailing of questionnaires was sent to those FF/Ps who had not yet responded. Questionnaires were numbered for tracking returns so that respondents could be entered in the drawing, but names were not associated with the information provided. This separation was implemented in order to maintain complete confidentiality.

Analysis

To assure the quality of the data coding, 52% (194) of the questionnaires were checked for accuracy by the SRL data reduction coordinator. Only five errors were found, yielding a very satisfactory error rate of .04%. As an additional quality check, frequencies were run on all the variables after half of the questionnaires had been coded to check for any unusual entries or skip problems. None was found.

Results of the Task Survey

In order to determine which of the 11 tasks should be selected for simulation in a controlled environment where ergonomic data could be gathered, the ratings for each task were plotted in two-dimensional space with one axis being frequency of performance and the other being strenuousness. Those tasks located in the upper right quadrant (high on both dimensions) were the tasks most likely to result in musculoskeletal injury production, and thus were selected for simulation. The four tasks in that quadrant were: Task 3 (Two workers transfer a patient from a bed to a stretcher using sheets); Task 6 (Two workers carry a patient on a backboard down a straight line of steps); Task 7 (Two workers carry a patient on a backboard around a curve in the stairway), and Task 8, (Two workers carry a patient in a stair chair down a straight line of steps. Also selected for simulation was one task that did not rate particularly high on strenuousness, but rated extremely high on frequency of performance because it occurs every time a patient is transported. This is Task 11 (Two workers transfer a patient from a stretcher to a hospital gurney using sheets). Once the Simulation Phase of the research was in progress, a sixth task was added to the set of simulations for some subject teams because of their use of a less-common piece of equipment -- a slat stretcher rather than a backboard -- for Tasks 6 and 7. This addition is described in the following section on the Simulation Phase of the project.

Phase 3: Postural Analysis

Method: Task Simulations

Approach

A set of six simulated emergency medical service (EMS) tasks was developed under the guidance of personnel from the consortium of MABAS III fire departments. The tasks identified via the survey conducted in Phase 2 were modeled such that the data collection requirements could be met while maintaining a close resemblance to the generic situations encountered by the firefighter/paramedics (FF/Ps). The six tasks selected for simulation included:

T1. Transferring a patient from a bed to a stretcher using a bedsheet (see Figures 1 and 2).

T2. Transferring a patient from a stretcher to a hospital gurney using a bedsheet (see Figure 3).

T3. Lifting and transporting a patient down a set of stairs and around a landing using a backboard (see Figures 4 and 5).

T4. Transporting a patient down a straight set of stairs using a stretcher (see Figure 6).

T5. Transporting a patient down a set of stairs and around a landing using a stairchair (see Figure 7).

T6. Transporting a patient down a set of stairs and around a landing using a slat-stretcher (see Figure 8). (This simulation was added at the simulation site after several teams of FF/Ps brought this piece of equipment, which was sometimes used by their fire departments.)

Tasks T3, T4, and T5 each contained a different combination of components. The components (subtasks) include:

S1. *Initial lift:* lift the backboard from the floor [see Figure 4(a)].

S2. *Initiate stair descent:* forward worker begins descending the stairs [see Figure 6(a)].

S3. *Mid-stair carry:* carry the victim down the straight portion of the stairs after both workers have begun descending the stairs [see Figure 6(b)].

S4. *Around-the-landing:* maneuver the backboard through the 90-degree turn and cramped space associated with a landing (see Figure 5).

Task T3 included all four of these task components. Task 4 included only components S2 and S3. Task T5 included components S2, S3, and S4. When the stretcher and stairchair were used (Tasks T4 and T5), the initial lift occurred at the

same time as the stair descent was initiated. Therefore, initial lift was not analyzed separately for Tasks T4 and T5.

Within each task there were two roles. (In the survey, the two roles were referred to as "Job 1" and "Job 2." In this report, the term "role" will be used in place of the terms "Job 1" and Job 2." Also, in the survey, the injured person being handled by the FF/Ps was referred to at the "patient." In this report, the term "victim" will be used in place of the term "patient.") For example, in the task of transferring a victim from a bed to a stretcher (Task T1), the following roles were identified in the initial interviews and validated by the survey as being strenuous and occurring frequently:

Role 1: Kneeling or standing on the bed and assisting the transfer of the victim by lifting the underlying bedsheet.

Role 2: Standing on the far side of the stretcher and pulling/sliding the victim toward yourself using the underlying bedsheet.

(See Figures 1 and 2. Also, see Page 6 of the Fire Service Survey. The Survey is enclosed as Appendix A.)

Subjects

Ten teams, each consisting of two experienced FF/Ps, were recruited from seven of the suburban fire departments participating in this study. The 20 volunteers, 17 male and 3 female, had been cross-trained as both firefighters and paramedics. Eighteen of the 20 worked full time for their respective fire departments. Two individuals came from a paid-on-call fire department. The mean height and weight of these individuals was 179 cm (range: 160-193 cm) and 87 kg (range: 57-118 kg), respectively. Each team's participation ranged from two to two-and-a-half hours. Prior to participating, the FF/Ps were briefed as to the tasks they would be asked to perform, and they signed an informed-consent form.

Apparatus/Environment

Data collection requirements included (a) an open stairway for videotaping, (b) a 90-degree (or greater) turn near the bottom of the stairs, followed by additional steps [the turn is equivalent to a landing], (c) an open staging area at the top of the stairs with adequate space for videotaping, and (d) open space in which to simulate the bed-to-stretcher-transfer and stretcher-to-gurney-transfer tasks. Through the cooperation of Fire Chiefs on our Advisory Board, we gained access to a moth-balled Naval Base building that suited our needs perfectly.

The stairway at the simulation site was considerably wider than that found in a typical residence in this part of the country. A rope was used to create an artificial "wall" one meter from the railing on the open side of the stairs. The rope was tied such that it was approximately one meter above the stairs and did not present a trip hazard. Each step had an 18 cm rise and a 30.5 cm run. In all, there were 19 steps including the landing, which required a 90-degree turn.

A conventional double bed, 193 cm long, 152 cm wide, and 53 cm high, was used to simulate the bed-to-stretcher-transfer task. The stretcher-to-gurney-transfer task was simulated by transferring the victim-dummy from one stretcher to another while the stretchers were in their raised positions (92 cm from the floor).

The victim was simulated by a dummy used for practice by one of the local fire departments. The weight of the victim-dummy was 471 N (48 kg). This weight is similar to that of a small female victim. While this weight is not representative of the entire population, we were continually reminded that heavier victims are typically handled by more than two workers. Moreover, to prevent fatigue we had to balance the weight carried against the number of carries we required of workers during our testing protocol.

Each team of FF/Ps brought their own equipment to use during the testing. This included a stretcher, a backboard, a stairchair, and straps necessary to secure the dummy to these transport tools. The variation in the weight of the backboards across departments, 62 to 71 N (mean = 69 N), largely depended upon how many straps were attached to the board. Stretchers varied between 303 and 401 N (mean = 368 N). Stairchairs showed the most variation across fire departments. Weights ranged between 80 and 107 N (mean = 94 N). The height of the chairs ranged between 94 and 137 cm. The handle height varied between 82 and 130 cm. It should be noted that approximately half of the FF/Ps elected not to use the handles on the stairchair during the testing procedure. Instead, they grasped the chair at the top of the seat-back. Two teams performed lifts with a slat-stretcher which weighed 71 N.

The two teams using the slat-stretcher indicated that they would never transport a victim down a flight of stairs using a conventional stretcher. This piece of equipment weighs the same as a backboard and is constructed out of canvas. It has wood strips, two meters in length, sewn into the fabric. This provides the slat-stretcher with longitudinal stiffness and lateral flexibility. The fabric handles sewn into the canvas allow the FF/Ps to carry the slat-stretcher with one hand. This frees their other hand to hold the banister during stair descent, possibly preventing a catastrophic fall. Moreover, the slat-stretcher affords the leader the advantage of walking forward down the steps.

Four video cameras were positioned to provide the best orthogonal views to the sagittal and frontal planes of the team of subjects. Trunk positions were determined with the Lumbar Motion Monitor (LMM) manufactured by Chattanooga Group, Inc. (Chattanooga, TN). This device measures the motion in the lumbar and thoracic sections of spine. Connections between the LMMs and the computers used for data collection were made through either a long wire or a radio link.

Procedures

Upon arrival, each member of a fire department team was instrumented with a LMM. The radio transmitter was provided to the LMM of the team member who volunteered to take on the transport tasks descending the stairs (walking backwards while carrying the victim). Strips of masking tape were placed over the ankles, the lateral side of each knee, the greater trochanters, the acromium processes, the mid-

lines of the elbows, and the mid-points of the wrist breadth dimensions. These strips were used in quantifying body postures from the videotapes.

The data collection started with the bed-to-stretcher-transfer task, followed by the stretcher-to-gurney-transfer task, and concluded with the three stair-descent tasks. The sequence of the stair-descent tasks -- with the stretcher, stairchair, and backboard -- was randomized for each team. Each task was repeated three times. Two teams indicated that they would never transport a victim down the stairs using a conventional stretcher. Instead, these teams frequently used the slat-stretcher, described earlier. Therefore, for one of these teams the slat-stretcher was substituted for the conventional stretcher. Data for this team was analyzed separately. The second team familiar with the slat-stretcher volunteered to perform extra trials so that more data could be obtained with this piece of equipment. Teams were allowed to select their own method for completing the task so long as the roles were consistent with those identified via the survey. One observed variation consisted of standing rather than kneeling on the bed during the bed-to-stretcher-transfer task. Another variation was that different FF/Ps used different arm postures as they descended the stairs backwards carrying a particular transport device (e.g., stretcher, backboard, or stairchair).

Hand forces were measured using a hand-held dynamometer (Wagner Instruments, Model FDV 100). For the bed-to-stretcher-transfer task and the stretcher-to-gurney-transfer task, the peak dynamometer readings were obtained as the force was slowly increased to overcome the frictional forces. Since the hand forces were not evenly distributed between the two roles in the victim transport tasks, hand forces were determined for each role. Once the distribution of forces was known for the backboard and stretcher, these forces were adjusted to accommodate the variations in equipment across teams.

Task Analysis Process

The tasks were broken down by task component, as shown in Table 2. Further, each task component included the two roles identified from the interviews and surveys. The videotapes were reviewed to obtain bi-planer postural data for the shoulders, and sagittal plane motion for all articulations except the torso. The torso postural data were obtained from the LMMs. For most task components, the reported postures were obtained from the most physically strenuous point in the performance of that task component. For example, in the transport-down-stairs-with-backboard task, the postures were analyzed as the subjects made the "initial lift" of the backboard from the floor [see Figure 4(a)]. In some of the transport task components (e.g., "mid-stair carry"), the trunk and arm postures were essentially static, thereby allowing the postures to be analyzed when the camera view was optimized. However, the averaged leg postures shown in the following section were more affected by the decision on where to freeze-frame the videotape for analysis.

Once the postural data were obtained from all the teams, those data were averaged across those teams that employed similar work methods. Where method variations could be identified, those subgroups were averaged separately. It should be noted, however, that there were typically a small number of observations in these subgroups (n = 1-3). Averaged data were used to construct figures for the postural

analysis. The figures were scaled using the average anthropometry presented by Marras and Kim (1993) as well as values obtained from other published sources (Webb Associates, 1978).

Results of Task Simulations and Postural Analyses

Bed-to-Stretcher-Transfer Task

Figures 1 and 2 show the two roles defined for the bed-to-stretcher-transfer task. One FF/P stood on the floor and reached across the stretcher (stretcher width = 56 cm) to grasp the sheet and pull the victim onto the stretcher. The other FF/P assisted by kneeling or standing on the bed and lifting the victim with the sheet.

For the individual in the pulling role, the measured applied force was 268 N. This force, while having a strong horizontal component, must also contain enough of a vertical component to assist the victim over the stretcher-bed interface and reduce the frictional force. This task required the pulling FF/P to work in a stooped posture at the point when the greatest force would be exerted. Trunk flexion angles averaged 54 degrees (sd = 20) at the initiation of the motion. The lower extremities were also used to prevent the stretcher from moving, thereby limiting the postures that could have been adopted during the patient transfer.

The FF/P positioned on the bed provided a lifting force to reduce the frictional force encountered by his or her partner and to assist the victim over the bed/stretcher interface. Kneeling on the bed, while providing stability to the FF/P's initial posture, did not allow for easy movement. As a result, most of these individuals completed the transfer with outstretched arms and significant forward spine flexion (49 degrees, sd = 18). This posture would create a large moment (torque) acting on the spine. Three FF/Ps performed the simulation by standing on the bed. By standing, the FF/Ps could potentially exert more of the lifting force with their legs while maintaining mobility, and hence achieve shorter reach distances at the completion of the transfer. However, the transfer task was still initiated with a significant amount of forward bending as the FF/P typically grasped the sheet near the victim. Figure 2 shows some representative observations obtained as FF/Ps in the bed role completed the two methods. Note the difference in the reach distance. While standing appears beneficial in a static analysis, the FF/P's stability may be compromised due to the mattress underfoot. Time should be taken to achieve a stable stance before the initial lift.

Stretcher-to-Gurney-Transfer Task

This task was the least strenuous of the tasks simulated. However, it is performed on nearly every EMS run. This task requires the victim to be lifted or dragged from one surface to the other (Figure 3). The FF/P in the "pull" role lifts and/or drags the victim toward the gurney and toward his or her torso. The FF/P in the "push" role primarily lifts the victim to reduce the frictional force.

In most cases, the exertion was coordinated by the two FF/Ps through a synchronizing count. This is particularly important because it reduces the likelihood that one individual will bear more of the load than s/he had anticipated. The forces measured with the dynamometer as the 467 N dummy was moved were 248 N for the

FF/P pulling and 258 N for the FF/P lifting. These were the peak force values captured during a slow transfer. Faster transfers would require that larger forces be applied. Likewise, a heavier patient would require larger forces. FF/Ps reported during interviews that the availability of assistance from hospital staff cannot be relied upon. However, if hospital staff happen to be available, they will generally assist in patient transfer.

The postures shown in Figure 3 represent the average postures found at the point the transfer is initiated. For the pull role, the trunk flexion derived from pelvic rotation and spine flexion was 22 degrees (sd = 8.7) and the arms were outstretched. In the push role, the initial posture was even slightly more stooped. This enabled the pushing FF/P to lift more with his/her back rather than relying on arm strength and shoulder strength.

The LMM detected lateral bending in some individuals in the pull role at the end of the exertion. This supplemental motion occurred as the lower extremities of the victim were transferred onto the hospital gurney. Usually this was not accompanied by any foot movement on the part of the FF/Ps. Firefighter/paramedics should be encouraged to align themselves with the lower extremities prior to this component of the lifting task, thereby eliminating the trunk lateral-bending component.

Transport-Down-Stairs-with-Backboard Task

This task comprises a series of task components. First, the victim on the backboard is lifted from the floor to waist level ("initial lift"). Next, after a short carry, the FF/Ps reach the stairs and "initiate stair descent". Once both the FF/Ps are on the stairs, the "mid-stair carry" subtask begins and continues until the landing is reached. At this point, postures change as the backboard is carried through the 90-degree turn in the stairs which we call the landing ("around the landing"). The two roles in the stair transport tasks have been defined as the "leader" and "follower" roles. The leader lifts the foot of the backboard (the end of the backboard where the victim's feet are placed) and carries the board while walking backward down the stairs. The follower lifts the head of the backboard (the end of the board where the victim's head is placed) and carries the board while walking forward down the stairs.

Figure 4(a) shows the most extreme postures, averaged across the 10 teams, observed during the initial lift. The FF/Ps in both roles approached the task by straddling their end of the backboard. The trunk was essentially maximally flexed, the elbows were essentially fully extended, and the knees were flexed approximately 90 degrees (sd = 21). The force distribution between the two FF/Ps indicates that the center of mass of the victim was closer to the FF/P at the head of the backboard.

Figures 4(b) and 4(c) show the initial sagittal plane postures as each FF/P started down the stairs. In the leader role, the trunk posture was essentially upright. The elbows tended to be flexed to maintain the victim in a more horizontal orientation and to provide clearance for the legs as the leader was beginning to step backwards down the stairs. The first couple of steps taken were accompanied by approximately 10 degrees of side bending (sd = 3) and 11 degrees (sd = 1) of twisting motion within the torso. This motion primarily occurred as the leader turned to view the stairs below him. In the follower, these motions were reduced to approximately 5-6 degrees (sd =

2) in each direction. The follower's elbows were more extended than the leader's and the trunk was more upright. For both roles, the trunk and upper extremity postures were essentially unchanged throughout the descent of the remaining stairs. Relative to the follower, the leader continued to show slightly more twisting and side bending of the torso, as s/he made repeated visual checks of the stairs.

The landing required a 90-degree turn. The still images from the video, seen Figures 5(a) and 5(b), show that the trunk was typically upright to hyper-extended, twisted, and laterally bent as the leader backed around the corner. Most of the FF/Ps in this role had their elbows flexed an average of 73 degrees (0 degrees being a straight arm) (sd = 29). Two individuals elected to carry the backboard in a raised position with the elbows flexed approximately 120 degrees, thereby bringing the board up to near chin level. This variation in method may have reduced the horizontal distance from the hands to the spine, and hence reduced the forward bending moment acting on the spine. Unfortunately, LMM data was only available for one of these individuals. It showed greater twisting and lateral bending, 17 and 19 degrees respectively, than found with the lower arm posture (12 degrees twisting (sd = 4) and 7 degrees of lateral bending (sd = 2). This occurred because, as the FF/Ps proceeded through the landing with the lower arm posture, they could rotate their shoulders to shift the board laterally rather than use trunk motion. Without the arms raised, the effectiveness of the shoulder rotation would be greatly diminished.

Transport-Down-Stairs-with-Stretcher Task

For purposes of analysis, this task was broken into two task components: (a) "initiate stair descent" [see Figure 6(a)] as the stretcher was rolled off the top of the stairs, and (b) "mid-stair carry" [see Figure 6(b)], the actual activity of descending the stairs. Discussions with the participating FF/Ps confirmed survey results which indicated that, if the rescue required lateral shifts in addition to transport down a straight flight of stairs, a stretcher would not be used. Therefore, the "around-the-landing" component of the transport-down-stairs-with-stretcher task was not simulated.

The individual in the leader role of the first task component [see Figure 6(a)] "initiated stair descent" from a position two-to-three stairs below the plane of the floor on which the stretcher was standing. This lowered position resulted in only an average of 24 degrees (sd = 16) of trunk flexion during the initial lift. There were 9 degrees of twisting (sd = 1) and lateral bending (sd = 4) motion measured by the LMM during the lift. This occurred primarily as the FF/P reached for the stretcher or when a visual check of the stairs was performed. The leader lifted 48 percent of the combined weight of the victim and the stretcher. This weight averaged 404 N across the stretchers used.

Relative to the leader, the FF/P in the follower role showed more forward bending of the spine as the stretcher was lifted (49 degrees; sd = 29). Generally, there was very little twisting or lateral bending of the torso accompanying the follower's lift. The torso flexion, combined with moderate degree of shoulder flexion (42 degrees; sd = 35) and small amount of elbow flexion (20 degrees; sd = 19), allowed the hands to be positioned just in front of the knees at the point the stretcher was lifted. The follower lifted 52 percent of the combined weight of the stretcher and the victim, which was 431 N.

Once on the stairs, the postures of both FF/Ps were much more erect [see Figure 6(b). By extending the shoulders 17 degrees (sd = 11) and flexing the elbows 84 degrees (sd = 6), the leader raised the stretcher away from his or her legs and held it close to the torso. Alternatively, the stretcher was carried by the leader in an arms-raised posture -- see Figure 6(d). This lift was initiated with the hands near shoulder level, through a combination of shoulder and elbow flexion, and with greater forward bending of the torso (mean = 36 degrees) [see Figure 6(c)]. Once lifted, the stretcher remained in a more horizontal orientation as it was carried down the stairs. The leader's hands were approximately the same distance horizontally from the spine as with the conventional method. Thus, the moment introduced by the 467 N was equivalent once the stretcher was lifted. However, the lifting process would increase the moment placed on the spine, because of the additional forward bending.

Transport-Down-Stairs-with-Stairchair Task

Three components of this task were studied: (a) "initiate stair descent," (b) "mid-stair carry," and (c) "around-the-landing." [See Figures 7(a) and 7(b)]. The total weight of stairchair and victim used in this test averaged 555 N. Of this, the leader and the follower carried 38% and 62% of the load, respectively.

At the top of the stairs, the chair was typically rolled to a position near the edge of the top step and tilted prior to lifting. The leader bent forward an average of 34 degrees (sd = 15) during the initial lift -- see Figure 7(a). The handle locations were more varied on the stairchairs than on any other type of equipment. Typically, the handles were in close proximity to the frame. However, on one model the handles for the leader extended approximately 30 cm to provide separation between the FF/P and the victim's lower extremities. Often the FF/P's feet were vertically separated by one stair as the chair was lifted. This allowed some of the lifting force to be generated by the lower extremities and helped the leader to maintain fore-aft stability. The follower's role changed at this point from one primarily of pushing to one of lifting. The torso was flexed slightly forward (15 degrees; sd = 16) and the elbows were flexed about 22 degrees (sd = 17). This nearly-straight arm posture was maintained by the follower during the "mid-stair carry" -- see Figure 7(b).

As the carry progressed, the trunk postures tended to be erect in both roles. The leader's elbows were flexed approximately 100 degrees (sd = 18), whereas the follower's elbows were flexed only 28 degrees (sd = 28). Thus, even though the leader carried less of the combined victim and chair weight, the flexed-arm posture increased the moment acting on the spine. Similarly, the compression predicted with the Three-Dimensional Static Strength Prediction Model (3DSSPM), developed by the University of Michigan, was 13 percent larger (Lavender et al., 1997). These postures were maintain through the landing to the point at which the stairchair was placed on the ground. As the chair was lowered, the leader's trunk flexed 31 degrees (sd = 17), whereas the higher handles on the back of the chair only required 10 degrees (sd = 10) of forward bending by follower.

Transport-Down-Stairs-with-Slat-Stretcher Task

Figures 8(a) and 8(b) show the "initial lift" of the slat-stretcher from the floor and the "mid-stair carry", respectively. The leader is using the one-handed method of

carrying. The "initial lift" is very similar to that found when lifting a backboard, although with slightly less forward bending at the point that the load is experienced by the FF/Ps. As with the initial lift using the backboard, the stretcher and victim are straddled so that the legs can be used to provide some of the lifting force, and so that the hands can be kept close to the torso in order to minimize the resulting moment placed on the spine.

The advantage of the slat-stretcher is that, depending upon the weight of the victim and the strength of the FF/P, it can be carried down the stairs with the leader facing forward -- see Figure 8(b). Generally, the posture was upright with a small degree of shoulder extension in the arm supporting the stretcher. However, it should be noted that this method was only observed in one FF/P. The leader of the second team that used the slat-stretcher descended the stairs backwards in a manner that was very similar to that observed with the backboard. While carrying the slat-stretcher with one hand may reduce the safety risk, the strength capacity of the leader's supporting upper extremity and contra-lateral back muscles may be exceeded with this method, potentially leading to a muscle-strain type of injury.

Phase 4: Biomechanical Task Analyses

Method

Approach

Data obtained from the simulation phase of the study were used in this last phase.

Biomechanical Task Analyses

The postural data were extracted from the videotapes using the cameras with the most orthogonal view for the given task component. Body segment orientations were expressed in terms of the coordinate system specified within the University of Michigan's Three-Dimensional Static Strength Prediction Model (hereinafter referred to as 3DSSPM). The three-dimensional trunk postures were obtained from the Lumbar Motion Monitor (LMM). This required the transformation of the trunk flexion angle so that it would be consistent with the 3DSSPM system.

Each task component was modeled for each individual in the simulation using the 3DSSPM. Each FF/P's height and weight were entered into the Model. The Model was then scaled according to these anthropometric dimensions. The hand forces were assumed to be an even distribution of the forces measured with the dynamometer. Postures in the computer model were adjusted according to each subject's measured posture. The computer model used these data to compute the net static moment at each articulation. These moments were then compared with population strength data for each of the articulations to determine the percentage of the population with similar anthropometric characteristics that would be capable of performing the modeled exertion. Therefore, the Model yields the percentage of the population who can develop the estimated moments at each articulation (strength capacity) to perform each muscular exertion. Tasks in which strength becomes a

limiting factor should be considered as putting people at risk for overexertion type injuries (Chaffin, 1979).

Compression values were computed by the 3DSSPM software for the intervertebral disc between the fourth and fifth lumbar vertebrae using the 3D trunk model developed by Bean et al. (1988). Compression values were compared with the compression tolerance limits used by NIOSH (1981) in the initial version of the lifting guidelines.

The Trunk Motion Logistic Regression Model (LRM) developed by Marras et al. (1993) was used to quantify low-back-disorder (LBD) risk based upon the trunk motion and dynamometer data. This model uses the following five factors to determine the probability that the observed task is representative of a high-LBD-risk task: the lifting rate per hour, the average twisting velocity, the maximum load moment during the lift, the amount of forward (sagittal) bending during the lift, and the peak lateral bending velocity. The trunk motion data were obtained from the LMMs, the moment data were obtained by multiplying the dynamometer reading by the maximum horizontal reach distance, and the lifting rate was set to a value of 5 to represent the average lifting rate per hour.

Descriptive statistics were computed for each of the quantities calculated above to show the overall trends in the data. Strength capacities extracted from the 3DSSPM output were not normally distributed, so the median value has been presented to describe the central tendencies in these data. Mean values have been used for all other quantities. The probabilities obtained with the LRM, the strength percentages, and the compression estimates were compared across conditions (tasks, task components, methods, and roles) by using analyses of variance (ANOVAs) and the Mann-Whitney non-parametric tests.

Results of the Biomechanical Task Analyses

Bed-to-Stretcher-Transfer Task

Strength limitations were most apparent for the FF/Ps standing on the far side of the stretcher. The median values across the 10 FF/P's modeled indicated that only 71 percent of the population would have adequate back strength to perform the modeled task. However, only 17 percent of the population has enough strength in the shoulders to abduct the arms into the modeled posture (30 degrees of shoulder abduction). Lifting and pulling the 47 kg dummy onto the stretcher resulted in spine compression values at L4/L5 between 3700 N and 7600 N (mean = 5476 N). Therefore, all compression values observed during the performance of this task in the stretcher-side role exceeded the NIOSH Action Limit (AL) of 3434 N. Some values even exceeded the Maximum Permissible Limit (MPL) of 6377 N. Figure 9 shows that the spine compression values were significantly greater ($p<.001$) for the stretcher-side role as opposed to the bed-side role.

Strength in the upper extremities and the back were not limiting factors for the FF/Ps kneeling or standing on the bed. Spine compression values were 45 percent less (see Figure 9) while anterior shear forces were nearly 90 percent greater in the standing (stooped) posture compared with the kneeling posture.

The LRM indicated that the bed-to-stretcher-transfer task is a high-risk task with respect to low back disorders. The mean probability values, averaged for the FF/Ps on the stretcher and the bed sides of the transfer were 96 percent and 89 percent, respectively (see Figure 10). The primary factors responsible for these high probability values were: (a) the moment due to the extreme reach, and (b) the degree of forward bending. The greater reach on the stretcher side probably accounts for the significantly higher risk ($p<.01$) associated with this role. Moreover, both roles showed some moderately fast twisting motions (over 8 degrees/second), which also served to elevate these probabilities. The probability values, on average, were less (82%) in the FF/Ps who elected to stand as opposed to kneel on the bed (90%), although, due to the small sample size, this was not statistically tested. The difference was primarily due to faster twisting and side-bending motions in the kneeling posture.

Stretcher-to-Gurney-Transfer Task

Only 86% of the population would have adequate back strength to pull the victim off the stretcher and onto the gurney. This pulling role was significantly more demanding on the back and shoulder abduction strength than for the FF/P on the stretcher side ($p<.05$), with only 35% of the population having sufficient shoulder abduction strength to perform the pulling role in this task. Knee strength, however, was a limiting factor in the FF/P on the stretcher side during the transfer. Only 80 percent of the population would have adequate knee flexion (hamstring) strength to perform this function.

Estimated spine compression was 56% higher ($p<.001$) for the FF/P on the gurney side (3350 N) as compared to the stretcher side (2147 N) of the transfer (see Figure 9). On the other hand, anterior shear was over six times greater for the FF/P on the stretcher side (323 N) than for the FF/P on the gurney side (52 N) during the transfer ($p<.001$).

Probabilities generated by the LRM were 78% and 73% for the stretcher side and gurney side of this transfer task, respectively (see Figure 10). The primary factor in the Model driving these high probability values was the moment associated with the extended reach distances.

Transport-Down-Stairs-with-Backboard Task

This task and its components are illustrated in Figures 4(a), 4(b), and 4(c). The backboard transport task was broken into four components: (a) "initial lift" from the floor, (b) "initiate stair descent," (c) "mid-stairs carry," and (d) "around-the-landing." The starting height of the handles during the initial lift was between 2 and 5 cm. The resulting low-level lift was significantly more strenuous for the FF/P lifting the head of the backboard ($p<.05$). Only 92% of the population would have the back strength necessary to complete the lift at the head of the backboard with the 467 N victim-dummy. Figure 11 shows that the compression forces between the fourth and fifth lumbar vertebrae were also significantly greater ($p<.01$) for the FF/P at the head of the backboard (5224 N) as opposed to the foot of the backboard (3955 N). Similarly, the anterior shear was significantly greater ($p<.05$) when lifting the head of the backboard. The TMLRM output yielded a significantly higher mean probability value of 58% for the head of the backboard as opposed to 44% for the foot of the

backboard (see Figure 12). The primary factor distinguishing between these two roles was the weight lifted and the resulting moment that was generated about the spine (69 Nm at the head of the backboard versus 41 Nm at the foot of the backboard).

In the "initiate stair descent" component of this task, knee strength could be a limiting factor for up to 10% of the population, especially for a person in the "leader" role. Analysis of the median values indicated that the upper extremity strength requirements were not of significant concern. Spine compression values during this task component were much lower than during the "initial lift" (see Figure 11). The FF/P at the head of the backboard experienced an average of 2826 N of spine compression, whereas the FF/P at the foot of the backboard only experienced 2763 N of spine compression. This task component was of relatively low risk from the standpoint of the LRM (see Figure 12). The probability that this task component was representative of a high-risk task was only 26% for the role at the foot of the backboard and 27% for the role at the head of the backboard. While the moment contribution to the Model was greater at the head (supporting the upper body weight), FF/Ps in the "leader" role (descending the stairs backwards) displayed more rapid twisting motions as they turned to view the stairs below them.

Once the FF/Ps reached the "mid-stair carry" component of this task, the probability value increased slightly for the FF/P in the follower role to 33%, primarily due to an increase in the trunk's twisting velocity. The probability value for the leader remained essentially unchanged (Figure 12). For either role, upper extremity strength was not a limiting factor. However, according to the 3DSSPM output, knee strength could potentially be a limiting factor for up to 14% of the population. On average, back strength was generally more of limiting factor for the leader than the follower role, although not significantly so. Spine compression values were relatively low, and were very similar for these two roles (2535 N for the leader, 2549 N for the follower).

In the "around-the-landing" component of this task, FF/Ps in the leader role showed two variations in arm postures which affected spine loading [see Figures 5(a) and 5(b)]. Most FF/Ps in the leader role (n = 8) continued through the landing carrying the backboard between waist and elbow level. Two leaders elected to raise the backboard to approximately chin level during this task component. There were no significant differences between the two roles with regard to joint strength requirements, nor was there any difference due to the method variation just described. Spine compression values did not differ significantly by role, but were on average larger, on average, than those experienced while in the "mid-stair carry" component of the task (mean = 3185 N across all FF/Ps observed -- see Figure 11). The probability values from the Logistic Regression Model associated with the "around-the-landing" component of this task are greater than the values for the "mid-stair carry" component (see Figure 12). However, the values mark this as a relatively low-risk task, relative to the other strenuous EMS tasks frequently performed by FF/Ps. Trunk motion data for FF/Ps who raised the board to chin level while in the role of leader during the "around-the-landing" component of this task were available from only one individual. But this one data point suggests that there was a considerably elevated risk as this task component was performed (see Figure 12).

Transport-Down-Stairs-with-Stretcher Task

This task is illustrated in Figures 6(a), 6(b), 6(c), and 6(d). Back strength becomes a limiting factor when a victim is transported down the stairs using a stretcher. Only half (53%) of the population would have adequate strength to carry a 467 N victim (weight of our victim dummy), on the stretcher, in the leader role. A smaller percentage of the population (41%) would have enough back strength to "initiate stair descent" carrying the stretcher in the raised position. This position was used by three of the FF/Ps performing this task component in the role of leader. Furthermore, in the more common, waist-level carrying position [see Figure 6(b)], under half (45%) of the population would have enough elbow-flexion strength to support the combined load of the stretcher and victim. Conversely, 99% of the population would have the elbow strength necessary to carry the stretcher in the raised position. This explains why, in part, the raised posture was selected. The raised posture reduces the moment acting at the elbow by reducing the horizontal distance between the grasping point on the stretcher and the elbow's axis of rotation. However, the raised posture tend to increase the shoulder adduction moment, thereby increasing the shoulder abduction strength requirements to the point that only 37% of the population would have adequate shoulder strength to use the raised posture in this task.

The back strength demands on the FF/P in the follower role during the "initiate stair descent" component of the task, while significantly lower ($p<.01$), were still quite high. Only 76% of the population would be able to perform this task component in the follower role. Associated with the high strength demands were large spine compression forces. These were 4500 N for the leader carrying the stretcher at waist level, and 5700 N for the leader carrying the stretcher at chin level (see Figure 11). Both values exceed the AL proposed by NIOSH. The compression for the follower was 4700 N, which was not significantly different from that for the leader carrying the stretcher at waist level. As the FF/Ps moved from the "initiate stair descent" component to the "mid-stair carry" component, the spine compression values declined: down to 3700 N for the waist level posture and 4000 N for the chin level posture. This reduction occurred at the same time as the reach distances were minimized and the trunk postures became more upright.

The probability values generated by the LRM were greatest for the FF/P in the leader role in the "initiate stair descent" component of this task (see Figure 12). An analysis of variance indicated a significant interaction effect between the task component and the role within that component ($p<.001$). In essence, the LBD risk indices for this task component were extremely high for FF/Ps in both the leader role (97%) and the follower role (85%) -- (see Figure 12).

Ninety-two percent of the population would have enough back strength to carry the stretcher down the stairs once the stairs have been initiated. Elbow strength could be problematic for up to 13% of the population performing in this capacity. In the leader's role, on the other hand, which was less demanding than the initial lift at the top of the stairs, back strength would still be problematic for 31% of the population when carrying the stretcher at waist level, and for 19% of the population when carrying the stretcher at chin level. Similar trends and trade-offs between elbow and

shoulder abduction strength exist across these method variations as found in the previous task component.

Transport-Down-Stairs-with-Stairchair Task

Initiating the stairs with the stairchair was significantly ($p<.05$) more demanding on the back for the leader as compared to the follower. Only 82% of the population would have adequate back strength to perform the leader's task, as opposed 91% who could likely perform the follower's task. In general, this task component was within the strength capacity of the upper extremities. Spine compression forces followed a similar pattern. The leader's spine compression was, on average, 37% greater than that experienced by the follower (see Figure 11).

An analysis of the variance in the outputs from the logistic regression model indicates that there were significant differences between the roles within this task ($p<.001$), and between components of the task ($p<.05$), but that these relationships did not change across task components ($p>.05$). The probabilities associated with the leader's role went from a maximum of 57% during the initial descent component, to 48% during the carry, and down to 37% as the landing was negotiated. The probabilities for the FF/P in the follower role were 32%, 32%, and 27% for the same sequence of task components, respectively (Figure 12).

Transport-Down-Stairs-with-Slat-Stretcher Task

Based on analysis of data from a very small sample ($n = 2$), only 83% of the population would have enough strength in their back to lift the head of the slat-stretcher. Once lifted, however, the handling of the slat-stretcher with the victim dummy (weight = 467 N) would be within the back and upper-extremity strength capacities for most of the population until a landing had to be negotiated. While 92% of the population would have adequate back strength, only 88%, 81%, and 82% of the population would have the necessary shoulder-abduction strength, elbow strength, and knee-extension strength, respectively, to perform the follower role in the landing. Spine compression values were relatively low except for the initial lift. However, this analysis was based on only two FF/Ps in each role.

The LRM indicated that use of the slat-stretcher resulted in similar probability values as those found when handling the backboard during the initial lift. However, the slat-stretcher values for the remaining task components compare favorably with those reported for the other transport tasks.

DISCUSSION

This study has described the postures adopted and the forces applied by FF/Ps as they simulated frequently-performed strenuous work tasks. Studies have shown that in both nursing and fire service settings, patient handling and transport tasks are physically demanding and often tax the musculoskeletal system to its limit (Gagnon et al., 1986, 1987; Jensen, 1987). What makes it more challenging to design ergonomic improvements in the FF/P job is the variation that exists from one EMS work setting to the next (i.e., from one EMS run to the next). But when the EMS

tasks are broken down into components, there are several components that are common across most EMS runs. For example: (a) victims are often found in bed, (b) victims must often be transported down stairways, (c) stairways often include landings and a corresponding change in direction, and (d) most EMS runs terminate with the transfer of the victim from the stretcher to a gurney at the hospital. Thus, we believe that risk factors can be identified and effective injury control measures can be developed by breaking frequently-performed strenuous EMS tasks down into their component parts.

During the simulations, FF/Ps were permitted to vary the method by which the task was performed if the variation was consistent with the task description used in the survey phase of this study. The only exception to this policy occurred when two teams offered to demonstrate the slat-stretchers that they regularly used.

Most of the variations in method during the transport tasks with the backboard and stretcher involved the leader raising the transport device to shoulder level, instead of carrying it at waist level. The raised position permitted the victim to be carried in a more horizontal orientation on the stairs. When the backboard was being carried around a 90-degree turn (landing), the raised position did allow tall leaders to guide the backboard over the railing on the inside of the turn. For leaders not tall enough to lift the backboard over the railing, the raised backboard position simply led to increased side bending and twisting in the torso. The raised position may reduce the static load on the elbow-flexing muscles during the carry down the straight portion of the stairs. On the other hand, it may reduce the stability of the leader's stance, because of the elevation of the victim's center of mass relative to that of the leader.

The other notable method variation that occurred during the simulation was where the FF/P on the bed during the bed-to-stretcher transfer elected to stand on the bed rather than kneel. Biomechanically, this puts the FF/P in a much stronger position. The muscles that extend the knees are now capable of exerting force and the muscles that extend the hips and spine are at a stronger position within their range of motion. This method also allows the lifter greater mobility and lessens the need for hand positions far from the torso at the completion of the lift. Further analysis is needed, however, before recommending this method to the fire service. The optimal hand position on the sheet relative to the victim must be determined so that the force the FF/P can exert to grip and lift is maximized while the risk of musculoskeletal injury is minimized.

In terms of the biomechanical analyses, this study has documented the muscular strength capacities, the mechanical loading of the spine, and the relative risk of low back disorder associated with several EMS task identified by FF/Ps as being frequently performed and strenuous. It was shown that a significant proportion of the population would not have the strength required to perform a number of these tasks. This should be cause for concern, given the relatively low weight of the simulation dummy handled in this study. Clearly, with heavier victims even a smaller percentage of the population would have the strength capacity to perform these relatively frequent EMS tasks.

Likewise, these same tasks were shown to have components similar to those found in jobs with a high historical risk of low back disorder. Large moments are

common to all the most strenuous task components. These moments are introduced by (a) heavy loads, as in the case of the transporting the victim down stairs on a stretcher, or (b) extended reaches, as in the victim transfer tasks. Most of the particularly strenuous task components also included substantial forward bending of the torso (e.g., initial lifts or the initiation of the stairs).

The results suggest that, whenever possible, personnel should avoid using a stretcher to transport victims down stairs. When a stretcher must be used, additional personnel should be recruited to carry out the task (e.g., use four FF/Ps instead of two). This will intervention will reduce the weight borne -- and the moment experienced -- by each FF/P.

Overall, the data from tasks involving the stairchair suggest that it poses less of a hazard when transporting victims down stairs than does the stretcher. The entry for the initiation of the stairs showed only a 56 percent probability. This indicates that the stairchair should be recommended for use when transporting victims down stairs, if their medical condition permits.

The backboard is an acceptable alternative to the stairchair and the stretcher for carrying victims down stairs, especially if there are no sharp turns in the descent. In the present study, the initial lift was modeled as being from the floor. This lift is strenuous, and thus is risky. If the degree of lift can be reduced -- as when the victim is already lying on an accessible, elevated surface (like a bed), then risk in using the backboard is reduced. Carrying the backboard through the landing could be facilitated through some interventions in backboard design. Most backboards are fixed in length and are made long enough to accommodate the taller people in the population. If the board were adjustable in length, then the board could be made shorter when shorter victims were carried. The reduction in length would facilitate maneuvering in confined spaces, and when moving through sharp turns in hallways and stairways. A waist harness system could be developed that would allow the board to be carried in a hands-free mode. By transferring the weight directly to the pelvis the spine remains unloaded during the transport task.

An obstacle to assessing the ergonomic risk among fire service personnel was our inability to systematically record the work of FF/Ps during actual EMS runs. Legal, ethical, and logistical considerations prevented our doing so. We need to develop a methodology whereby we could obtain realistic data in a systematic and efficient way in a in a controlled setting. That challenge was met. In the present study we demonstrated a useful methodology (i.e., a progression from interview to survey to simulation) for capturing reliable and valid data for assessing ergonomic risks among workers whose jobs cannot be systematically observed in field settings.

This analysis has indicated several areas in which design changes could be incorporated into future equipment. The patient transfer task from bed to stretcher and from stretcher to gurney would be facilitated by having a low friction interface available that bridges the gap between the two surfaces. By building flaps coated with a low friction surface into the equipment, the sliding of victims from one surface to another would be facilitated, and the need to actually lift the victim would be reduced.

The limited testing with the slat-stretcher was useful in that it really highlighted the obvious benefits of the leader walking down the stairs facing forward. Designers of emergency response equipment should consider the use of waist harness systems where backboards could be "clipped" in. This would have three principle benefits: First, the leader is facing forward looking at the steps. Second, the hands are free to hold the railing. Third, the weight of the victim is placed directly on the pelvis rather than the standard transmission through the arms and spine. Along these same lines a backboard with a pivot that allows up to 20 degrees of frontal plane motion at the hip level would facilitate transporting a victim through a landing on a set of stairs. While such a board would need a mechanism to prevent this motion should this region need to be rigid, in many situations this flexibility in the board would reduce the stress placed on the body as the board is jockeyed around corners. Likewise, developing a board that can be adjusted in length may relieve some of the same stresses at least when shorter victims are carried.

Limitations to the Present Study

There are three major limitations to the present study which need to be discussed. First, the weight of the victim dummy was relatively low compared to the average weight for an adult in the United States. We believe, however, that the victim-dummy weight was heavy enough for us to sample realistic working postures. We believe that the postures sampled are consistent with those that FF/Ps use when handling heavier victims.

A second limitation of the present study is that the biomechanical loading of the spine was computed with a static model, thereby resulting in low estimates of the true spine compression and shear forces experienced during some of the task components modeled. This means that the dynamic and inertial forces acting on the body segments were neglected in the present analyses. However, previous studies (e.g., Tsuang et al., 1992) suggest that the dynamic force contributions should have been relatively modest, given the combined weights of the victim dummy and the EMS equipment.

The third limitation pertains to the quality of the simulations. Ideally, these observations would be obtained under real emergency conditions. It is clear that this cannot be done without interfering with the quality of EMS service overcoming numerous legal and ethical obstacles. The simulations were developed under the guidance of an advisory panel of Fire Chiefs from MABAS Division III of the Illinois Mutual Aid Box Alarm System. Their expertise helped to ensure that the simulated tasks were representative of the typical EMS situations encountered by their personnel. Thus, we are confident that what we have learned from this study is applicable EMS tasks encountered in the real world.

CONCLUSION

Fire service workers must routinely handle very high loads when performing EMS tasks. The present study, by analyzing the postures and forces applied during frequently-performed strenuous EMS tasks, has indicated promising targets for injury control efforts. The fire service has often dealt with high loads on EMS runs by simply

using more personnel to make a particular lift or carry. However, the present study shows that there are plenty of opportunities for engineering changes to EMS equipment that could reduce musculoskeletal injuries.

The present study demonstrated a reliable and valid method for assessing ergonomic risk among workers whose tasks would be difficult to study during actual work operations. The study surveyed fire service personnel to learn which EMS tasks they find to be the most frequently-performed and strenuous ones. The study then determined the muscular strength requirements, the mechanical loadings of the spine, and the relative risks of low back disorder associated with components of those EMS tasks. The study found that strength limitations would prevent a significant proportion of the population from performing these tasks. This finding should be cause for concern, given the relatively low weight of the simulation dummy used in this study.

Finally, research team members and study participants hypothesized interventions to reduce the risk of musculoskeletal injury associated with EMS tasks. The next step for researchers and fire service personnel working on the injury problem is to test the interventions hypothesized in the course of this study.

ACKNOWLEDGMENTS

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REFERENCES

Andersson, G. B. J. (1997). The epidemiology of spinal disorders. In J. W. Frymoyer (Ed.), The adult spine: Principles and practice, 2nd Edition (93-141). Philadelphia: Lippincott-Raven.

Andersson, G. B. J., Pope, M. H., Frymoyer, J. W., & Snook, S. (1991). Epidemiology and cost. In M. H. Pope, G. B. J. Andersson, J. W. Frymoyer, & D. B. Chaffin (Eds.), Occupational low back pain: Assessment, treatment, and prevention (pp. 95-113). St. Louis: Mosby.

Bigos, S. J., Battie, M. C., Spengler, D. M., Fisher, L. D., Fordyce, W. E., Hansson, T., Nachemson, A. L., & Zeh, J. (1992). A longitudinal prospective study of industrial back injury reporting. Clinical Orthopaedics, 279, 21-34.

Cady, L. D., Bischoff, D. P., O'Connell, E. R., Thomas, P. C., & Allan, J. H. (1979). Strength and fitness and subsequent back injuries in fire fighters. Journal of Occupational Medicine, 21, 269-272.

Cady, L. D., Thomas, P. C., & Karwasky, R. J. (1985). Program for increasing health and physical fitness of fire fighters. Journal of Occupational Medicine, 27, 110-114.

Chaffin, D. B. (1979). Manual materials handling: The cause of over-exertion injury and illness in industry. Journal of Environmental Pathology and Toxicology, 2, 269-272.

Cohen, A. (1989). Perspectives on self-protective behaviors and work place hazard. In N. E. Weinstein (Ed.), Taking care: Understanding and encouraging self-protective behavior. New York: Cambridge University Press.

Conrad, K. M., Balch, G. I., Reichelt, P. A., Muran, S., & Oh, K. (1994). Musculoskeletal injuries in the fire service. AAOHN Journal, 42(12), 1-10.

Davis, P. O., Dotson, C. O., & Santa Maria, D. L. (1982). Relationship between simulated fire fighting tasks and physical performance measures. Medicine and Science in Sports and Exercise, 14, 65-71.

Department of Health and Human Services. (1986). Proposed national strategy for the prevention of musculoskeletal injuries (DHHS Publication No. 89-129). Washington DC: Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health.

Doolittle, T. L., & Kaiyala, K. (1986). Strength and musculoskeletal injuries of firefighters. Annual Conference of the Human Factors Association of Canada (pp. 49-52). Richmond, British Columbia.

Doolittle, T. L. (1979). Validation of physical requirements for firefighters. (Technical report prepared for the Seattle Fire Department and Office of Management and Budget).

Doolittle, T. L. (1989). Validation of a firefighter physical ability test. (Technical report for the City of Tacoma, WA).

Doormall, M. T. A. J., Drissen, A. P. A., Landeweerd, J. A., & Drost, M. R. (1995). Physical workload of ambulance assistants. Ergonomics, 38, 361-376.

Dotson, C. O., Santa Maria, D. L., Davis, P. O., & Swartz, R. A. (1977). Development of a job-related physical performance examination for fire fighters. College Park: University of Maryland.

Ellam, L. D., Fieldman, G. B., Fordham, M., Goldsmith, R., & Barham, P. (1994). The perception of physical fitness as a guide to its evaluation in firemen. Ergonomics, 37, 943-952.

Gagnon, M., Chehade, A., Kemp, F., Lortie, M. (1987). Lumbo-sacral loads and selected muscle activity while turning patients in bed. Ergonomics, 30, 1013-1032.

Gagnon, M., Sicard, C., & Sirois, J. P. (1986). Evaluation of forces on the lumbo-sacral joint and assessment of work and energy transfers in nursing aides lifting patients. Ergonomics, 29, 407-421.

Hilyer, J. C., Brown, K. C., Sirles, A. T., & Peoples, L. (1990). A flexibility intervention to reduce the incidence and severity of joint injuries among municipal fire fighters. Journal of Occupational Medicine, 32, 631-637.

Hogya, P. T., & Ellis, L. (1990). Evaluation of the injury profile of personnel in a busy urban EMS system. American Journal of Emergency Medicine, 8, 308-311.

International Association of Fire Fighters (1996). 1995 death and injury survey. Washington DC. Author.

Jensen, R. C. (1987). Disabling back injuries among nursing personnel: Research needs and justification. Research in Nursing and Health, 10, 29-38.

Karter, M. J., & LeBlanc, P. R. (1996). U.S. fire fighter injuries in 1995. NFPA Journal, 90(6), 56-67.

Lavender, S. A., Conrad, K. C., Reichelt, P. R., Meyer, F. T., & Johnson, P. W. Biomechanical analyses of frequently performed strenuous work tasks encountered by firefighter/paramedics. Manuscript submitted for publication.

LeCuyer, J. (1994). Where tools and people meet. Fire Chief, 34-41.

Lemon, P. W., & Hermiston, R. T. (1977). The human energy cost of fire fighting. Journal of Occupational Medicine, 19, 558-562.

Marras, W. S., & Kim, J. Y. (1993). Anthropometry in industrial populations. Ergonomics, 36, 371-378.

Marras, W. S., Lavender, S. A., Leurgans, S. E., Rajulu, S. L., Allread, W. G., Fathallah, F. A., & Ferguson, S. A. (1993). The role of dynamic three-dimensional trunk motion in occupationally-related low back disorders: The effects of workplace factors, trunk position, and trunk motion characteristics on risk of injury. Spine, 5, 617-628.

Matticks, C. A., Westwater, J. J., Himel, H. N., Morgan, R. F., & Edlich, R. F. (1992). Health risks to fire fighters. Journal of Burn Care Rehabilitation, 13, 223-235.

Praemer, M. A., Furner, S., & Rice, D. P. (1992). Musculoskeletal conditions in the United States. Park Ridge, IL: American Academy of Orthopaedic Surgeons.

Reichelt, P. A., & Conrad, K. M. (1995). Musculoskeletal injury: Ergonomics and physical fitness. In R. Duffy, J. Melius, & P. Orris (Vol. Eds.), Occupational medicine: State of the art reviews: Vol. 10(3). Firefighters. Philadelphia, PA: Hanley Belfus.

Romet, T. T., & Frim, J. (1987). Physiological responses to fire fighting activities. European Journal of Applied Physiology, 56, 633-638.

Stilwell, J. A., & Stilwell, P. J. (1984). Sickness absence in an ambulance service. Journal of the Society for Occupational Medicine, 34, 96-99.

Sullivan, C., & Yuen, J. (1986). Predictors of work-related back injuries among fire fighters. Proceedings of the Fifth International Symposium on Epidemiology in Occupational Health (p. 165).

Tsuang, Y. H., Schipplein, O. D., Trafimow, J. H., & Andersson, G. B. J. (1992). Influence of body segment dynamics on loads at the lumbar spine during lifting. Ergonomics, 35, 437-444.

Webb Associates (1978). Anthropometric source book: Volume II. National Aeronautics and Space Administration.

Table 1

SUMMARY OF SIGNIFICANT FINDINGS AND USEFULNESS OF FINDINGS BY SPECIFIC AIM

Aim #1: Identify Frequently Performed, Physically Strenuous EMS Tasks

Significant Findings:

- Interviewees nominated the 11 most frequently performed and strenuous EMS tasks.
- A survey (N = 374) confirmed that the 11 EMS tasks identified during interviews were the most strenuous and frequently-performed ones in the 14 participating fire departments.
- The 11 EMS tasks were ranked on a composite score derived from survey ratings of frequency and strenuousness.

Usefulness of Findings:

- The interview findings provided the content for the reliable and valid survey questionnaire developed in this study. The questionnaire can be used for ergonomic investigations in other fire service populations.
- The survey results guided the selection of tasks for the simulation phase of the study.
- The survey results provide statistical validation of the list of fire service EMS tasks most in need of ergonomic improvement.

Aim #2: Conduct Ergonomic Task Analysis

Significant Findings:

- The task simulations produced reliable and valid ergonomic data about EMS work.
- Work postures for frequently-performed, strenuous EMS tasks were recorded and quantified.
- Forces applied by FF/Ps as they performed the strenuous EMS tasks were calculated.
- Strength limitations and spine compression forces for each EMS task were calculated using the University of Michigan Three-Dimensional Static Strength Prediction Model.
- The relative risks for low back disorder (LBD) associated with each EMS task were calculated using the Trunk Motion Logistic Regression Model developed at Ohio State University.

Usefulness of Findings:

- The simulation methodology developed here will allow further investigation of EMS tasks that cannot be observed during real operations because of practical, legal, and ethical constraints.

- The following three categories of findings indicate the risk of three different categories of injuries associated with each EMS task component. This information can be used to generate cost/benefit analyses for proposed work method or equipment redesign interventions targeted at each task component. The cost/benefit analyses can then be used to determine the relative priority of different ergonomic interventions.

  - The LBD risk analysis identified the EMS task components that contribute the most to the development of cumulative trauma back injuries.

  - The strength limitation calculations indicated the EMS task components during which musculoskeletal overexertion injuries are most likely to occur.

  - The spine compression calculations indicated the EMS task components during which disc-related back injuries are most likely to occur.

- Task analyses provide a basis for task-specific training and physical-conditioning programs.

Aim #3: Hypothesize Methods to Reduce Musculoskeletal Stress in Riskiest EMS Tasks.

Significant Findings:

Based on the ergonomic task analyses, the following equipment modifications (and related work method changes) are hypothesized to be feasible ways of reducing the risk of musculoskeletal injuries during frequently-performed, strenuous EMS tasks:

- A waist-supported, hands-free system for backboard transport.

- An articulated backboard with a locking mechanism.

- An adjustable length backboard with a locking mechanism.

- A low friction bed-to-stretcher interface.

- A tri-wheel stairchair.

Usefulness of Findings:

- The hypothesized modifications provide specific targets for future research efforts.

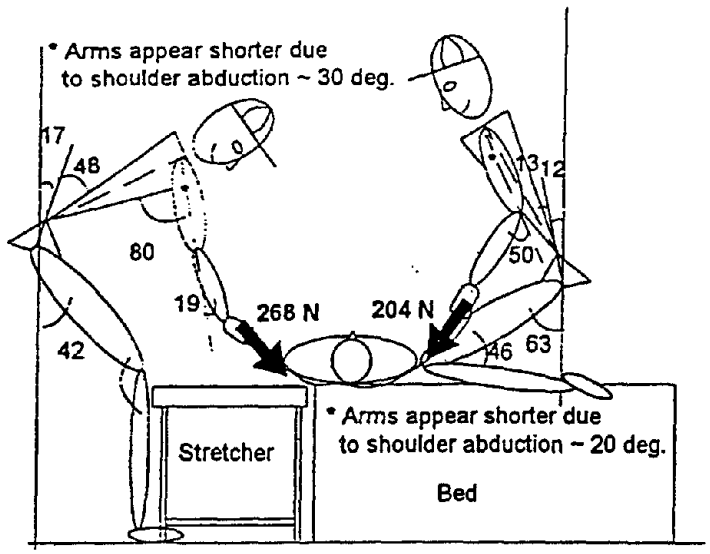
- The hypothesized EMS equipment and work-method modifications would be relatively simple ones to build and test.

Table 2.

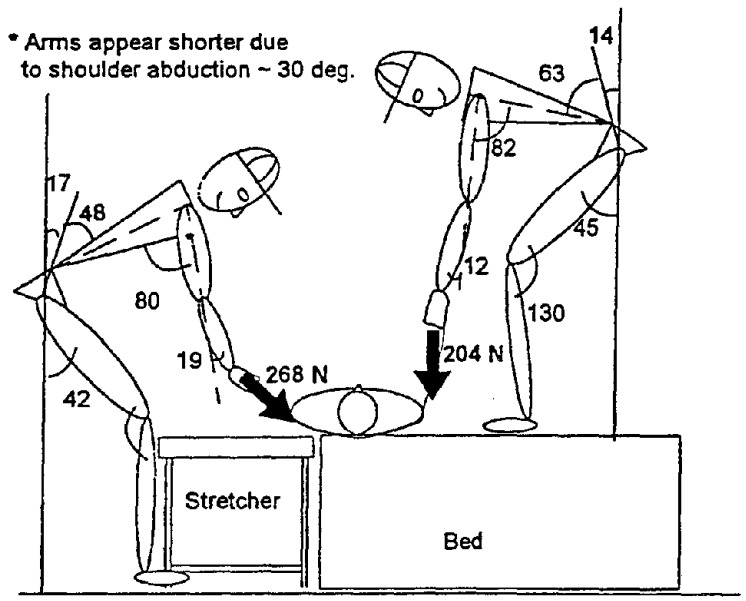
Task components performed during transport tasks involving stairs

Transport Task	Initial Lift	Initiate Stair Descent	Mid-Stair Carry	Around The Landing
Stairchair		X	X	X
Backboard	X	X	X	X
Stretcher		X	X	
Slat-Stretcher	X	X	X	X

Note. (All tasks, excepting the slat-stretcher transport, were selected on the basis of both interview and survey data.)



(a)



(b)

Figures 1(a) & 1(b). The Bed-to-Stretcher-Transfer Task. Figure 1(a) shows the kneeling method. Figure 1(b) shows the standing method.

(a)

(b)

Figure 2(a) & 2(b). The Bed-to-Stretcher-Transfer Task. Figure 2(a) shows the kneeling method. Figure 2(b) shows the standing method. The video images show differences between the kneeling and standing postures as the firefighter/paramedic on the bed completes the last strenuous component of the task.

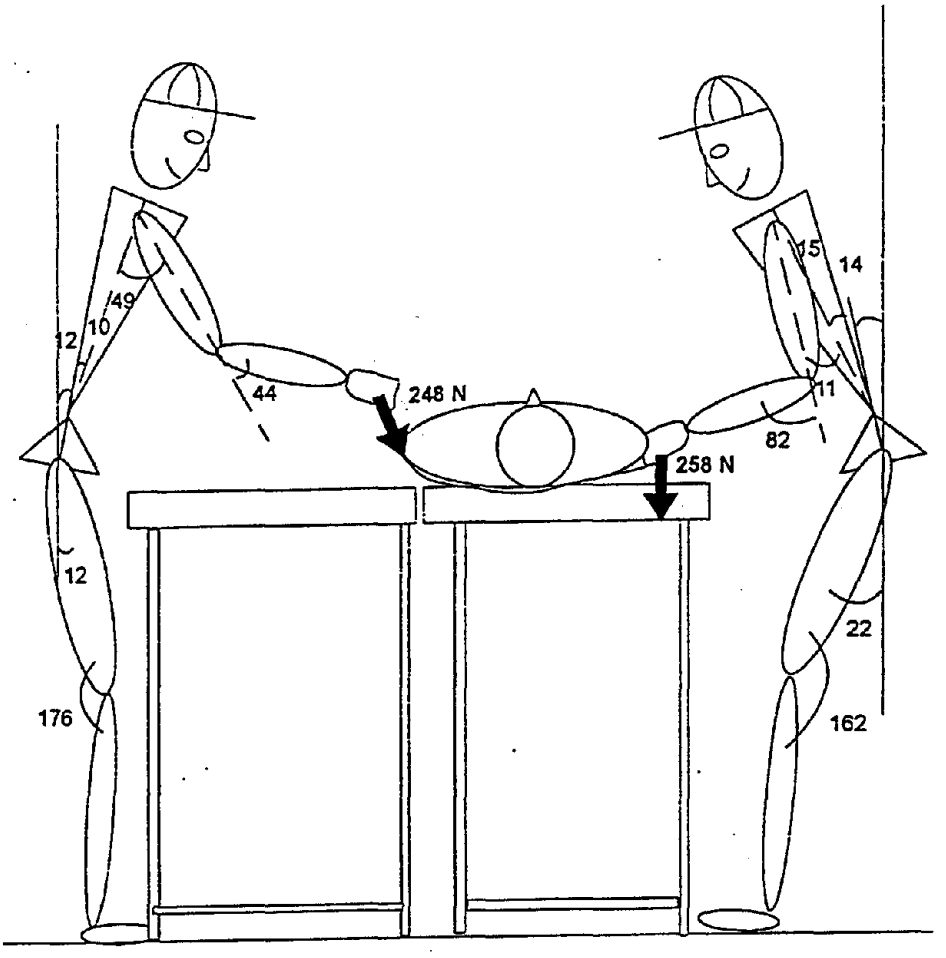
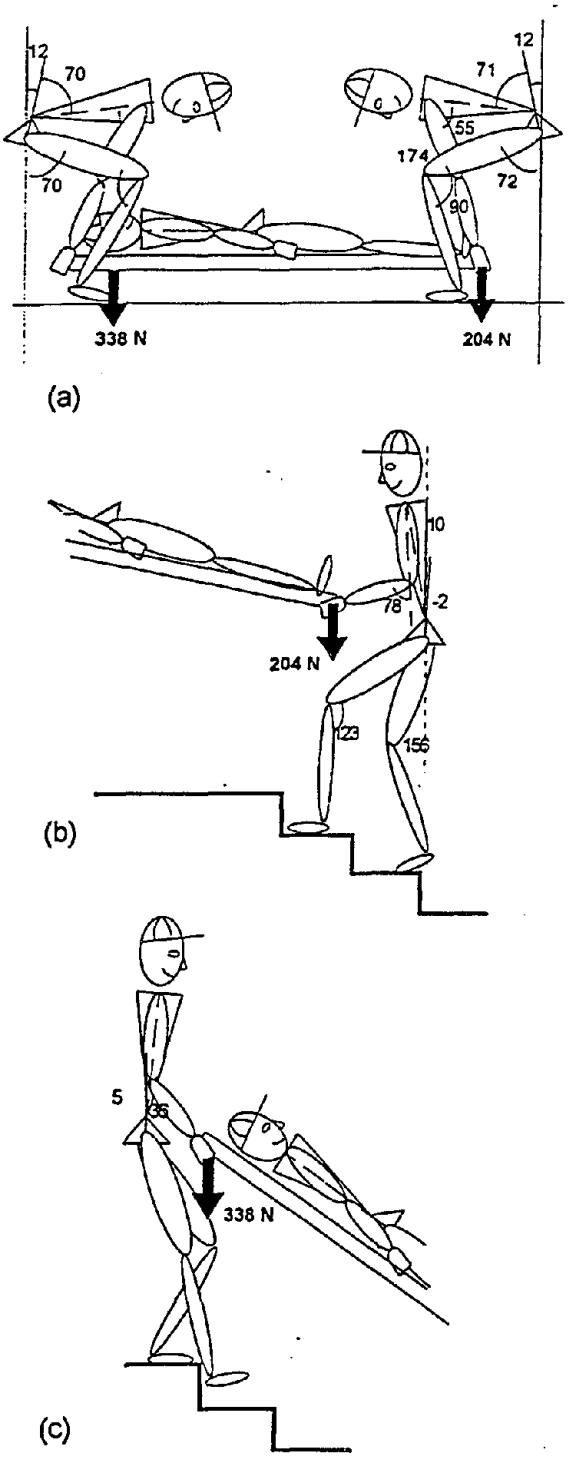
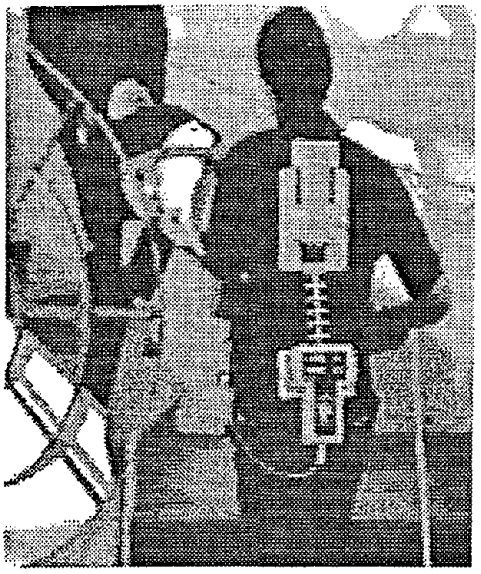


Figure 3. The Stretcher-to-Gurney-Transfer Task. The firefighter/paramedic (FF/P) on the left in this figure both lifts and pulls the victim. The FF/P on the right assists by lifting the victim.

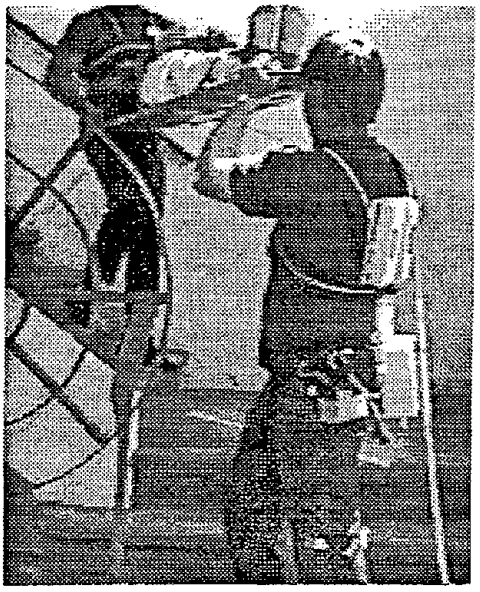


Figures 4(a), (b), & (c). The Transport-Down-Stairs-with-Backboard Task. Figure 4(a) shows the first component of the task ("initial lift"). Figure 4(b) shows the second component ("initiate stair descent"). The firefighter/paramedic (FF/P) shown in Figure 4(b) is the "leader" in the task. The leader descends first and makes the descent walking backward. Figure 4(c) shows the third component ("mid-stair carry"). The FF/P shown in Figure 4(c) is the "follower" in this task. The follower makes the descent walking forward.

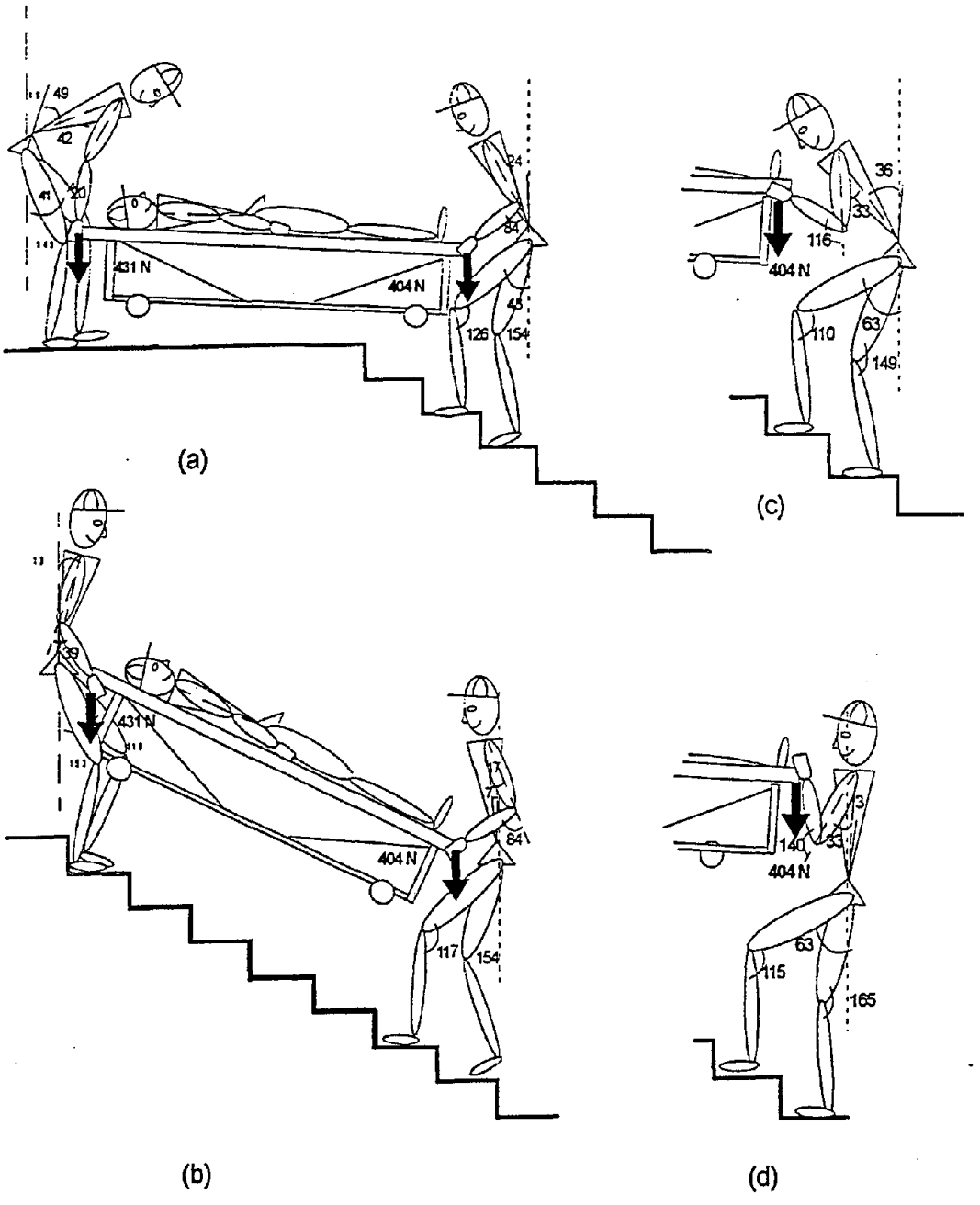
(a)



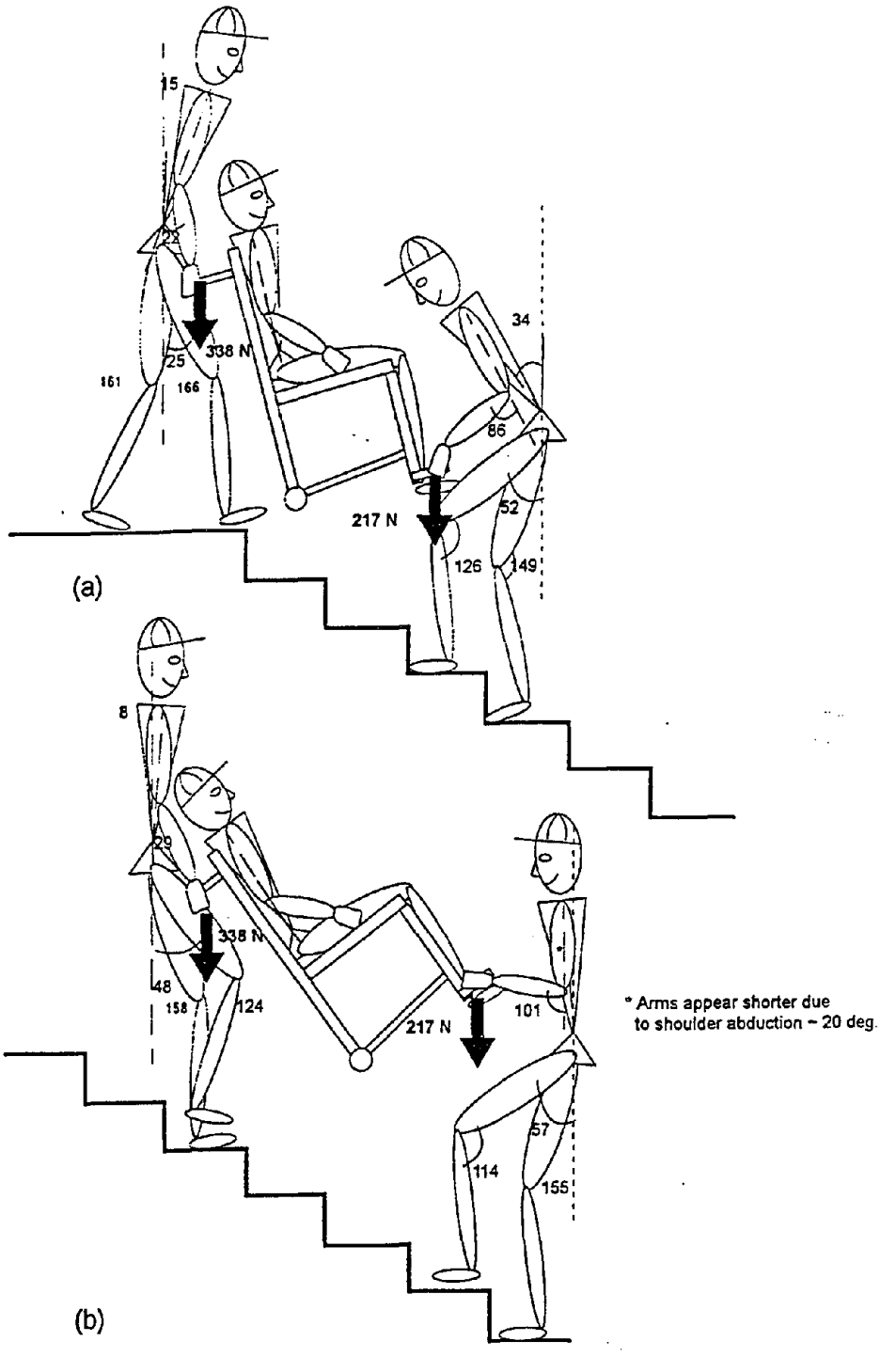
(b)



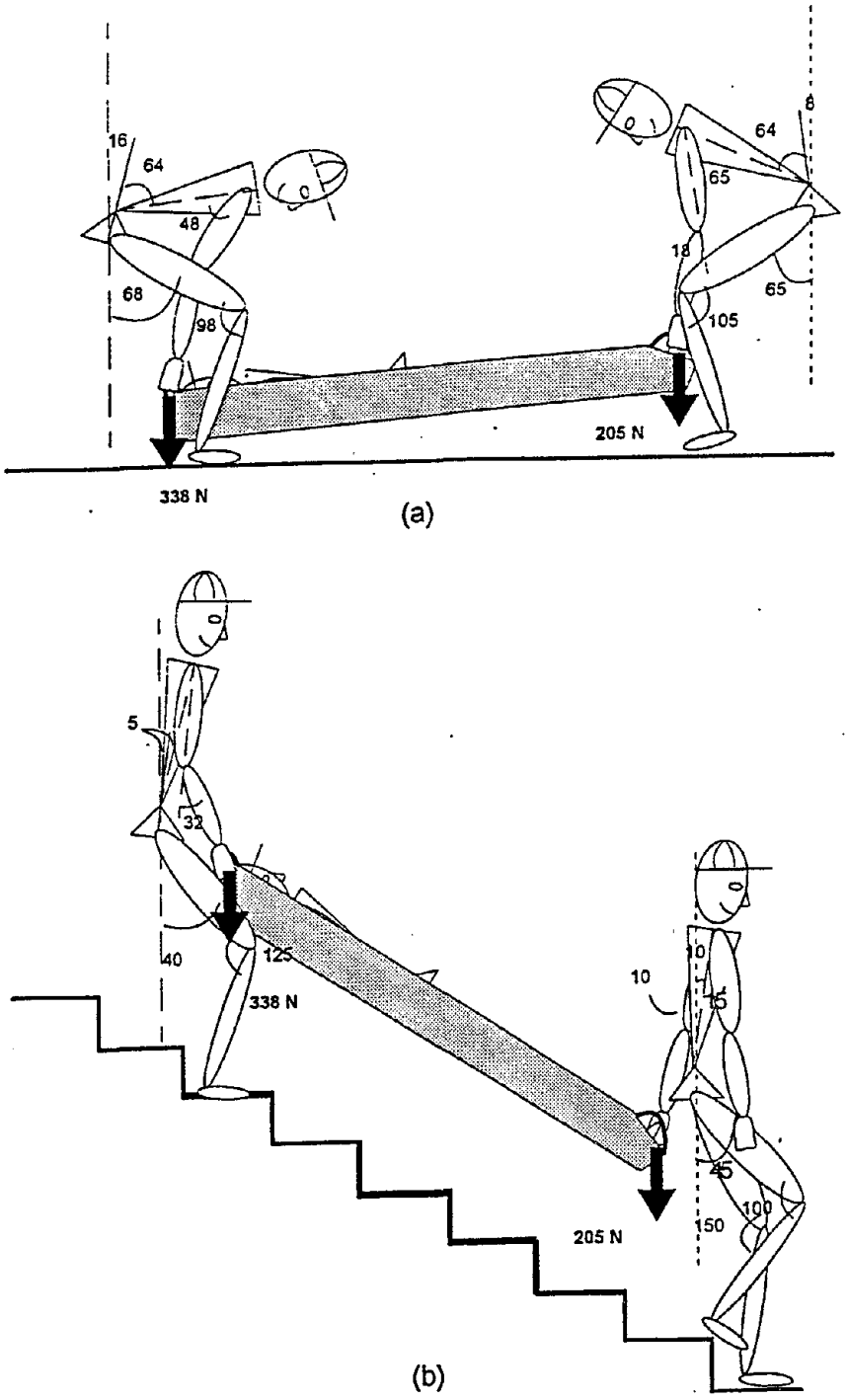
Figures 5(a) & (b). The Transport-Down-Stairs-with-Backboard Task. Shown are two different postures the firefighter/paramedic (FF/P) in the "leader" role may take as he negotiates the fourth component of the task ("around-the-landing"). (The leader is the FF/P on the right in both figures.) In Figure 5(a) the leader has his arms in the lowered position. In Figure 5(b) the leader is performing the same task component with his arms raised. Figure 5(a) shows the Lumbar Motion Monitor strapped to the leader's back. The cable to the radio transmitter can be seen emerging from the bottom of the unit. Figure 5(b) shows the radio transmitter hanging from a harness over the leader's left hip.



Figures 6(a), (b), (c), & (d). The Transport-Down-Stairs-with-Stretcher Task. Figure 6(a) shows the first component of the task ("initiate stair descent"). Figure 6(b) shows the second component ("mid-stair carry"). The lower firefighter/paramedic is the "leader" in the task. Figure 6(b) shows the leader carrying the stretcher at waist height, with the elbows extended. Figure 6(c) shows the leader shifting postures, to one in which the elbows are flexed and the stretcher is held at chin height, as shown in Figure 6(d).



Figures 7(a) & (b). The Transport-Down-Stairs-with-Stairchair Task. Figure 7(a) shows the first component of the task ("initiate stair descent"). Figure 7(b) shows the second component ("mid-stair carry"). Both firefighter/paramedics (FF/Ps) are shown using the handles built into the stairchair. The lower FF/P is the "leader" in the task. The upper FF/P is the "follower" in the task.



Figures 8(a) & (b). The Transport-Down-Stairs-with-Slat-Stretcher Task. Figure 8(a) shows the first component of the task ("initial lift"). Figure 8(b) shows the third component ("mid-stair carry"). The lower firefighter/paramedic (FF/P) is the "leader" in the task. The upper FF/P is the "follower" in the task. Figure 8(b) also shows the leader grasping the slat-stretcher with only his left hand during the "mid-stair carry." The right hand remains free. It can be used to grab hold of a railing or brace against a wall, if necessary.

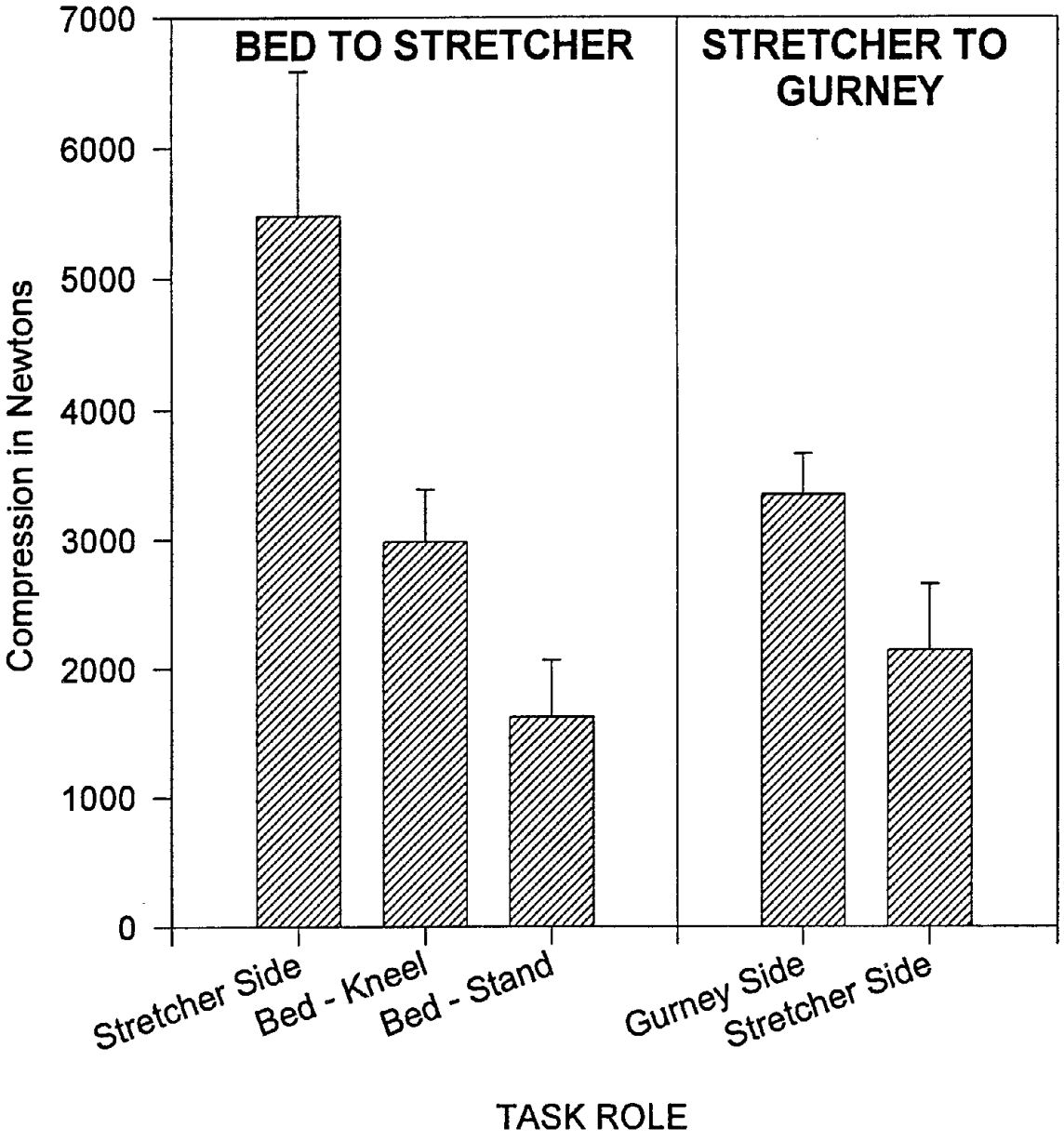


Figure 9. The mean compression values for the bed-to-stretcher and the stretcher-to-gurney tasks as a funciton of the role and method variations.

Figure 10. The probability that performing a specific role in a specific task component by a particular method is representative of a cluster of task performance elements associated with a high historical incidence of low back disorders. Each row of the table represents a different cluster of task performance elements. The different clusters are ranked from high to low in terms of probability values. The probability values are from the Logistic Regression Model.

TASK	COMPONENT		ROLE	METHOD	PROBABILITY
Stretcher	Transport	Initiate Stairs	Leader	Raised	98.3
Stretcher	Transport	Initiate Stairs	Leader	Normal	96.6
Bed-to-Stretcher	Transfer	Stretcher-Side	Pull	normal	96.2
Slat-Stretcher	Transport	Initial Lift	Follower	normal	95.4
Backboard	Transport	Initial Lift	Follower	normal	91.4
Bed-to-Stretcher	Transfer	Bed-Side	Push	normal	88.9
Stretcher	Transport	Initiate Stairs	Follower	normal	85.1
Stretcher	Transport	On Stairs	Leader	Normal	83.8
Stretcher	Transport	On Stairs	Leader	Raised	82.1
Stretcher-To-Gurney	Transfer	Stretcher-Side	Push	normal	78.2
Backboard	Transport	Initial Lift	Leader	normal	75.1
Stretcher-To-Gurney	Transfer	Gurney-Side	Pull	normal	73.4
Slat-Stretcher	Transport	Negotiate Landing	Follower	normal	73.1
Slat-Stretcher	Transport	Initial Lift	Leader	normal	70.5
Slat-Stretcher	Transport	On Stairs	Follower	normal	66.0
Slat-Stretcher	Transport	Initiate Stairs	Follower	normal	61.4
Stairchair	Transport	Initiate Stairs	Leader	normal	56.9
Backboard	Transport	Negotiate Landing	Leader	Raised	56.1
Stairchair	Transport	On Stairs	Leader	normal	48.0
Backboard	Transport	On Stairs	Leader	normal	39.5
Backboard	Transport	Initiate Stairs	Leader	normal	39.2
Stairchair	Transport	Negotiate Landing	Leader	normal	37.9
Backboard	Transport	Negotiate Landing	Follower	normal	37.2
Backboard	Transport	On Stairs	Follower	normal	35.7
Stairchair	Transport	Initiate Stairs	Follower	normal	32.2
Stairchair	Transport	On Stairs	Follower	normal	31.9
Stretcher	Transport	On Stairs	Follower	normal	31.8
Backboard	Transport	Negotiate Landing	Leader	Normal	29.3
Slat-Stretcher	Transport	On Stairs	Leader	One-hand	27.7
Slat-Stretcher	Transport	Negotiate Landing	Leader	One-hand	27.5
Stairchair	Transport	Negotiate Landing	Follower	normal	27.3
Slat-Stretcher	Transport	Initiate Stairs	Leader	One-hand	25.2
Slat-Stretcher	Transport	Initiate Stairs	Leader	Two-hand	24.0
Slat-Stretcher	Transport	On Stairs	Leader	Two-hand	18.7
Backboard	Transport	Initiate Stairs	Follower	normal	16.8
Slat-Stretcher	Transport	Negotiate Landing	Leader	Two-hand	13.2

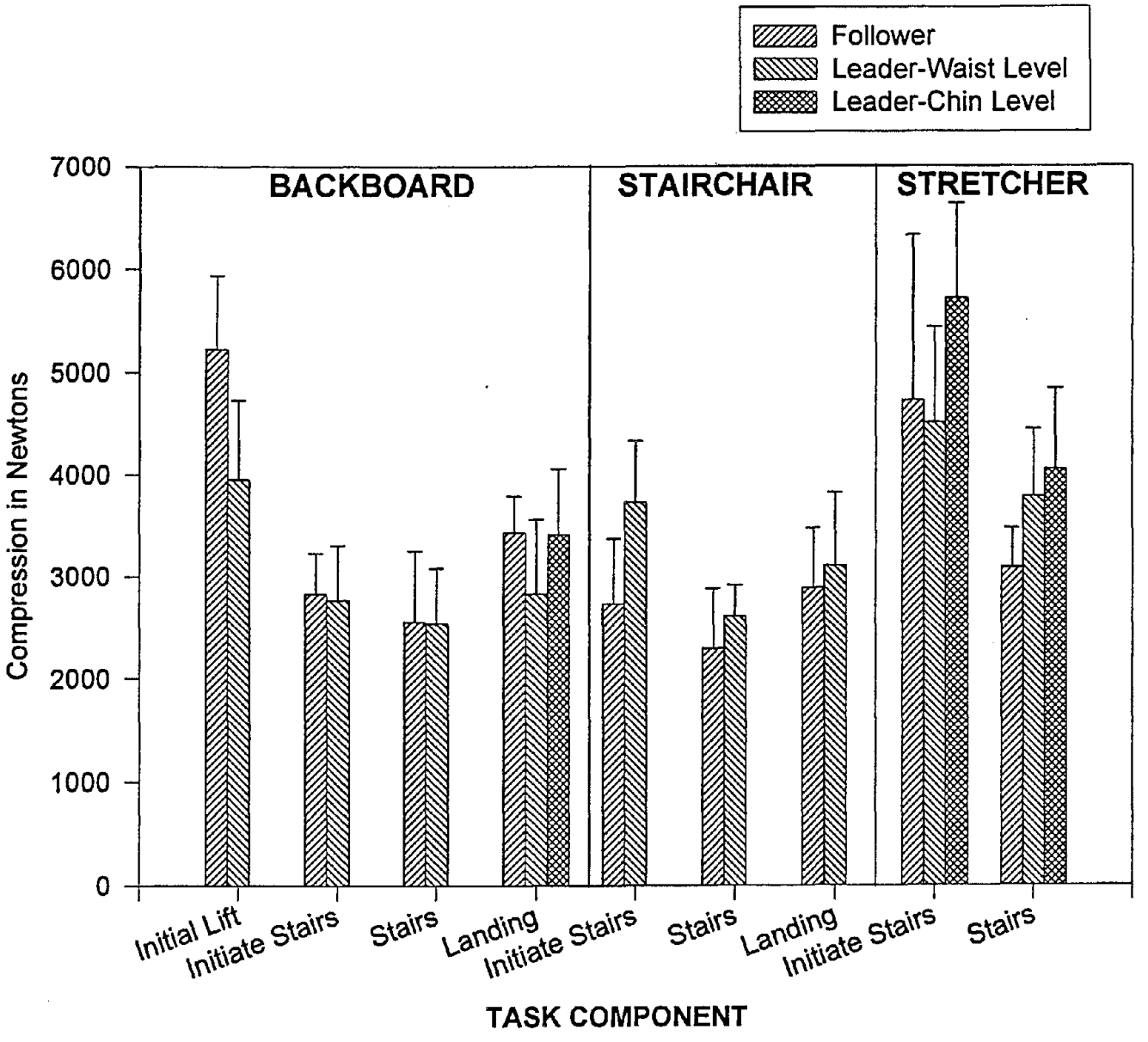


Figure 11. The mean compression values (Newtons) for the backboard, stairchair, and stretcher trasport tasks as a function of task component, role, and method variation.

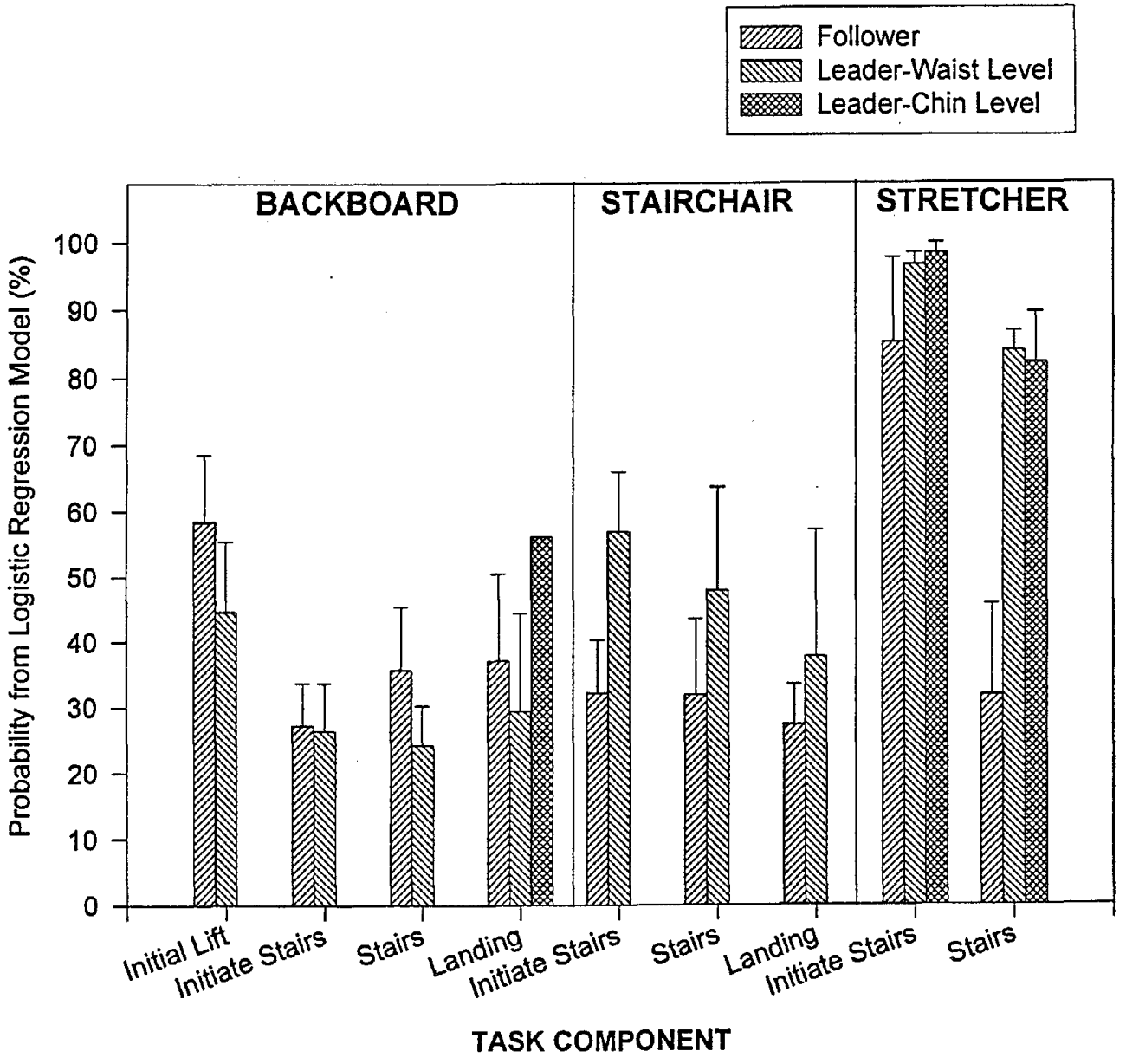


Figure 12. The mean probability values from the logistic regression model indicating the likelihood that the model tasks are representative of tasks with a high historical incidence rate of low back disorders.

PLANNED PUBLICATIONS

Conrad, K. M., Lavender, S. A., Reichelt, P. A., Meyer, F. T., Marks, B. Firefighters simulating frequently performed strenuous EMS tasks: Overview of methods and results.

Lavender, S. A., Conrad, K. M., Reichelt, P. A., Meyer, F. T., & Johnson, P. W. Postural analyses of firefighters simulating frequently performed strenuous EMS tasks.

Lavender, S. A., Conrad, K. M., Reichelt, P. A., Meyer, F. T., & Johnson, P. W. Biomechanical analyses of firefighters simulating frequently performed strenuous EMS tasks.

FIRE SERVICE SURVEY

SEPTEMBER 1995

Conducted by:
The Survey Research Laboratory
University of Illinois at Chicago

Principal Investigator:
Karen Conrad, Director
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INTRODUCTION TO THE EMS TASK SURVEY

EXAMPLE QUESTION:
Here is how the survey works: First, read the description of the task. Next, recall how often you do the jobs involved and how strenuous they are for you, **ON AVERAGE.** Finally, answer the four questions regarding each task. Below is an example for Job 1.

Sample Task
Two workers lift a patient on a backboard from the floor (ground) to the height of a stretcher that has its undercarriage fully extended. There are two jobs in this task.

JOB 1. Worker 1 squats at the head of the backboard, grasps it, and then straightens up, lifting the head of the backboard.

JOB 2. Worker 2 squats at the foot of the backboard, grasps it, and then straightens up, lifting the foot of the backboard.

Example A. Out of every 10 emergency calls, on approximately how many calls do you perform **JOB 1**?

Less than 1 call in every 10 ..... (1)

1-2 calls out of every 10 2

3-4 calls out of every 10 3

5-6 calls out of every 10 4

7-8 calls out of every 10 5

9-10 calls out of every 10 6

For example A, the firefighter has circled response 1 because he/she squats at the head of the backboard and lifts less than 1 time in every 10 calls, on average.

Example B. How physically strenuous is **JOB 1** for you?

Not strenuous 1

Somewhat strenuous 2

Strenuous ..... (3)

Very strenuous 4

For example B, the firefighter has circled response 3 because he/she feels that lifting an average-sized male patient up in this manner is strenuous. The firefighter would continue with the survey by answering the same questions imagining he/she was doing Job 2.

3. Out of every 10 emergency calls, on approximately how many calls do you perform **JOB 2**?

Less than 1 call in every 10 1

1-2 calls out of every 10 2

3-4 calls out of every 10 3

5-6 calls out of every 10 4

7-8 calls out of every 10 5

9-10 calls out of every 10 6

4. How physically strenuous is **JOB 2** for you?

Not strenuous 1

Somewhat strenuous 2

Strenuous 3

Very strenuous 4

Final Performance Report

Ergonomic Study of Fire Service Musculoskeletal Injuries

NIOSH Research Grant 5 RO3 OH03123-02

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TABLE OF CONTENTS

SIGNIFICANT FINDINGS

The significant findings of this study are discussed in terms of the three specific aims of the study. The first specific aim was to identify frequently-performed physically strenuous job tasks of firefighter/paramedics (FF/Ps) engaged in emergency medical service (EMS) tasks. Through a process of 29 qualitative interviews and a survey of almost 400 FF/Ps, this study validated a list of the most frequent and strenuous EMS tasks performed by FF/Ps. The 11 EMS tasks were ranked based on a composite score of survey ratings of frequency and strenuousness.

The second aim was to conduct an ergonomic task analysis. This study demonstrated the feasibility of producing reliable and valid data by simulating the tasks carried out on typical EMS runs. Work task data were captured on videotape and using Lumbar Motion Monitors (LMMs). These data allowed different postures representing separate components of the EMS tasks to be quantified. In addition, the forces applied by FF/Ps as they completed the simulated EMS tasks were quantified. Strength limitations were identified and spine compression forces were calculated using the University of Michigan Three Dimensional Static Strength Prediction Model (3DSSPM). Finally, the relative risks for Low Back Disorder (LBD) were determined using the Trunk Motion Logistic Regression Model (TMLRM) developed at Ohio State University.

The third aim was to hypothesize ways to reduce musculoskeletal stresses in the identified tasks. Based on the ergonomic task analysis, the following modifications are hypothesized to be feasible methods for reducing the risk of musculoskeletal injuries among FF/Ps.

- A waist-supported, hands-free system for backboard transport.
- An articulated backboard with a locking mechanism.
- An adjustable-length backboard with a locking mechanism.
- A low-friction bed-to-stretcher interface.
- A tri-wheel stairchair.

USEFULNESS OF FINDINGS

In terms of the first specific aim, the list of frequently-performed strenuous job tasks derived from the interview and survey phases of the study was used to select tasks for the simulation phase of the study. In addition, the reliable and valid survey questionnaire that was developed for use in this study can be used to investigate other similar fire service populations.

In terms of the second specific aim, the ergonomic task analysis process demonstrated a feasible way to conduct ergonomic research on tasks that cannot be systematically observed during actual operations because of practical, legal, or ethical constraints. The ergonomic task analysis identified the postures that put firefighter/paramedics (FF/Ps) at risk for musculoskeletal injury. The analysis also identified the tasks during which musculoskeletal overexertion injuries, or disc-related back injuries, are likely to occur. The simulations developed for this study could serve as the basis for task-specific training and physical conditioning programs. In fact, the Principal Investigator used the task analysis data from this study to help develop a physical-fitness intervention program for FF/Ps. That intervention is part of a current, NIH-funded study.

In terms of the third specific aim, the ways to reduce musculoskeletal injury that were hypothesized in the final phase of this study can be used to guide future research efforts. Furthermore, the hypothesized ways to reduce injury suggest design changes in EMS work methods and equipment that should be investigated.

The significant findings from this study, and the usefulness of those findings, are summarized in Table 1.

ABSTRACT

Ergonomic Study of Fire Service Musculoskeletal Injuries

Musculoskeletal injuries account for almost half of all injuries among the one million firefighters in this country. These injuries result in excessive absenteeism, costly medical claims, and disability. The handful of studies conducted on musculoskeletal injuries in the fire service have examined job tasks in relation to the physical requirements (e.g., aerobic capacity, flexibility, and strength) needed to perform fire suppression tasks. In actuality, today's firefighter is increasingly cross-trained as both a firefighter and a paramedic or an emergency medical technician. (This study refers to such cross-trained personnel as firefighter/paramedics [FF/Ps].) Such cross-training is effective, because these days a fire department can easily find that over 60% of its runs are for emergency medical services rather than for fire suppression. There is a need to examine the FF/P job from an ergonomic perspective and describe the biomechanical stresses encountered in the job. These stresses include handling heavy people (victims) and equipment, through lifting, twisting, stretching, and reaching.

The objective of the present study was to describe the frequently-performed strenuous emergency medical service (EMS) tasks that place the FF/P at risk for musculoskeletal injury and to hypothesize ways to reduce this risk. The study population was 542 FF/Ps from 14 suburban fire departments. The study was conducted in four phases. The content domain of frequently-performed physically strenuous tasks was identified in the first two phases. In the first phase, an initial list of tasks was identified through structured interviews with a sample of 29 FF/Ps. (The interview was pilot-tested with 5 FF/Ps.) In the second phase, a list of the 11 most frequent and strenuous tasks identified in the interviews was validated through a mail survey returned by 374 (74%) of the FF/Ps. (The survey was pilot-tested with 24 FF/Ps.) In the third phase of the study, the 5 most frequently performed strenuous tasks identified in the survey (plus one additional task) were simulated and the working postures and the forces applied by the workers were recorded and described. Each task was simulated by 10 teams of FF/Ps who volunteered to participate. Video data were used to determine gross postures and movement ranges. More detailed kinematic data were obtained for the torso using the Lumbar Motion Monitor (LMM). In the last phase of the study, the biomechanical stresses were analyzed and the relative risk of low back disorder (LBD) was quantified. The end product of this study was the generation of hypothesized ways to reduce the risk of musculoskeletal injury associated with frequently-performed, strenuous EMS tasks. Finally, a subsequent study is proposed. The goal of the subsequent study will be to test the ideas for improving the design of EMS work methods and equipment that were generated in the final phase of the present study.

BODY OF REPORT

BACKGROUND AND SIGNIFICANCE

The fire service is one of the most hazardous industries in this country. Its work-related injury and illness rates exceed those for most other industries (International Association of Fire Fighters, 1996; Karter & LeBlanc,1996; Reichelt & Conrad, 1995). For example, the incidence of work-related injury in the fire service in 1995 is reported to have been 4.5 times that for private industry, with 37.6% of firefighters reporting injuries (International Association of Fire Fighters, 1996). In 1995, the National Fire Protection Association estimated that there were 94,500 fire service injuries that required medical treatment or resulted in at least one day of restricted activity (Karter & LeBlanc, 1996). In 1995, there were 9597 lost-work hours per 100 workers due to firefighter injuries (International Association of Fire Fighters, 1997).

Musculoskeletal injuries account for about half of all injuries among the one million firefighters in this country (International Association of Fire Fighters, 1996; Karter & LeBlanc, 1996). Musculoskeletal injuries result in lost worktime, costly medical claims, and even permanent disabilities and premature retirements. These injuries are primarily sprains, strains, and muscular pain, which occur most frequently to the back (Matticks, Westwater, Himel, Morgan, & Edlich, 1992). It is increasingly common for firefighters to be cross-trained both as firefighters and as paramedics or emergency medical technicians (EMTs). (This study refers to such cross-trained personnel as firefighter/paramedics [FF/Ps].) Accordingly, the above-noted statistics reflect injuries and illnesses that result from engagement in fire suppression, rescue, and emergency medical service (EMS) operations. Studies of non-firefighter paramedics and EMTs report similar statistics for musculoskeletal injuries (Hogya & Ellis, 1990; Stilwell & Stilwell, 1984).

The ranking of musculoskeletal injuries as the primary and most costly injury in the fire service parallels the case for U.S. workers in general (Andersson, Pope, Frymoyer, & Snook, 1991; Bigos, Battie, Spengler, Fisher, Fordyce, Hansson, Nachemson, & Zeh, 1992). For U.S. adults of working age (18-64 years old), the estimated cost of musculoskeletal conditions was $79 billion dollars in 1988 alone (Praemer, Furner, & Rice, 1992).

Research on Musculoskeletal Injuries in the Fire Service

There is little research on the full range of causal factors of work-related musculoskeletal injuries in the fire service. Fire service musculoskeletal injury research has focused on firefighters' engagement in physical fitness activities, particularly on flexibility activities. A large prospective study of Los Angeles County firefighters related pre-employment physical measurements to subsequent work-related back injuries (Sullivan & Yuen, 1986). This study concluded that trunk flexibility was the strongest protective factor against the occurrence of work-related back injuries. A flexibility intervention study by Hilyer, Brown, Sirles, and Peoples

(1990) concluded that improved flexibility among firefighters participating in an intervention program was associated with fewer joint injuries, less absenteeism, and lower worker compensation costs. That study suggested that mandatory flexibility training may yield positive outcomes in the short term. Work by Cady and colleagues also supports the association between physical fitness in firefighters and fewer musculoskeletal injuries (Cady, Bischoff, O'Connell, Thomas & Allan, 1979; Cady, Thomas, & Karwasky, 1985).

Doolittle and Kaiyala (1986) concluded that there was an inverse association between strength and musculoskeletal injury. This was the only firefighter study reviewed where an attempt was made to control for risk of exposure to musculoskeletal injury. In that study of multiple fire stations, exposure was defined as the number of hours spent on the fire scene per fire station. While this is an admittedly gross aggregate measure of exposure, it does represent acknowledgment that exposure needs to be quantified in studies examining associations between fitness and injury rate.

Fire service research:
Job task analyses to identify physical requirements for job

A few studies have examined firefighting tasks in relation to the physical requirements needed to perform the job (Davis, Dotson, & Santa Maria, 1982; Doolittle, 1979, 1989; Lemon & Hermiston, 1977; Romet & Frim, 1987). In their first study, Dotson, Santa Maria, Davis, and Swartz (1977) quantified the physiological and physical requirements of the structural firefighter. For this seminal study of 100 career firefighters, the Fire Training Offices of the Metropolitan Council of Governments in Washington, DC nominated a representative list of frequent and critical firefighting tasks. Five tasks from the nominated list were selected for use in the study. Performance of the five tasks was timed. Correlation analysis identified key variables relating physical performance and the simulated firefighting tasks. The two primary factors associated with high performance in the simulated tasks were high aerobic energy involvement and resistance to fatigue. The Dotson et al. (1977) study concluded that high muscular strength and endurance as well as near-maximal aerobic capacity were required to successfully complete the simulated tasks. (An electronic search of nine databases and a manual literature search in preparation for this report showed no additional publications on the topic).

Since the time of the Dotson et al. (1977) study, the five fire suppression tasks often used as a basis for job task analysis have remained essentially the same (stair/ladder climb, hose advance, simulated forcible entry/chopping, hoist evolution/standpipe hose load pull, and simulated victim rescue - dummy drag) (Davis et al., 1982). These tasks simulate the metabolic demands imposed on a firefighter during actual fire suppression work. The physical requirements identified by Davis et al. (1982) concerned primarily aerobic capacity, and to a lesser extent flexibility and strength. The purpose of the job task analysis work described was to identify physical requirements for the job, not to examine biomechanical risk factors for musculoskeletal injury.

The Need:
Task Analysis to Quantify Biomechanical Stressors Related to Musculoskeletal Injury Among FF/Ps

The few studies noted above examined firefighting tasks in relation to the physical requirements needed to perform job tasks. Their emphasis was on fire suppression tasks, not EMS tasks. Not only have firefighters always performed both fire suppression and EMS tasks, but today's firefighter is increasingly cross-trained both as a firefighter and as a paramedic or EMT. Such cross-training is effective, because today over 60% of fire department alarms are for emergency medical services rather than for fire suppression (International Association of Fire Fighters, 1996). Only one study was found that quantified the biomechanical stressors inherent in the EMS part of the job. It was an unpublished report, and it provided only sketchy details of the process (Doolittle, 1989).

The significance of the present study is summarized by the following points:

1. Musculoskeletal injury is the most common type of injury among this nation's one million firefighters.

2. In the nation's fire departments, FF/Ps are performing EMS tasks more frequently than they are performing fire suppression tasks. Yet, the biomechanical parameters involved in the performance of EMS tasks have not been quantified in a systematic way.

3. The present study used an ergonomic approach to identify the EMS tasks that expose FF/Ps to biomechanical stressors. The present study also quantified the biomechanical parameters of those tasks.

4. This study lays the groundwork for subsequent simulation studies by hypothesizing changes in work methods and equipment that should reduce the risk of musculoskeletal injury while performing EMS tasks.

5. The information obtained from the present study (and a proposed follow-up laboratory study) will form the basis for a comprehensive intervention study to reduce musculoskeletal injury among FF/Ps performing EMS tasks. The comprehensive intervention study will seek to alter manipulable factors located in the fire service worker, fire department policies and procedures, EMS work methods, and fire service equipment.

CONCEPTUAL FRAMEWORK

NIOSH's document on musculoskeletal injuries suggests that preventive strategies should take into account (a) workplace hazards, such as heavy lifting or repetitive, forceful manual twisting; as well as (b) behavioral or lifestyle factors, such as physical fitness activities (Department of Health and Human Services, 1986). The combination of worksite hazard control and worksite health promotion can clearly enhance the level of workers' health both on and off the job. Unfortunately, there is little research that comprehensively integrates worksite hazard control and health

promotion. Despite the contrasting nature of these two types of approaches, they are in fact complementary and can be synergistic (Cohen, 1989).

Taken together, both NIOSH's directive and the available research point to the need for a conceptual framework that integrates hazard control and health promotion approaches. Such an integration considers both personal factors (such as physical fitness) and workplace factors (such as biomechanical stressors) as contributors to the occurrence of musculoskeletal injuries.

The conceptual model that guided this study posits that desired health outcomes, such as reduced musculoskeletal injury, are determined by both individual factors and by factors beyond the individual. In this case, factors beyond the individual include the workplace and the external environment in which the emergency medical services are rendered (Conrad, Balch, Reichelt, Muran, & Oh, 1994). The model maintains that the factors are interrelated and that prevention efforts must be directed at both the individual and the workplace. In this study, the major workplace factors to be examined were biomechanical stressors created by the performance of FF/P tasks and the interaction with fire service equipment. The person factors were captured in the form of anthropometric measures. Situational factors at the scene of the emergency were also considered.

The conceptual model was a product of our preliminary focus group study (Conrad et al., 1994). The purpose of the focus group study was twofold: (a) to elicit firefighter/paramedics' perceptions, attitudes, and feelings about the personal, workplace, and uncontrollable situational factors that contribute to musculoskeletal injuries, and (b) to develop a collaborative relationship between university researchers and the fire service. It was felt that obtaining input and cooperation from fire service groups in the early phases of the research would help secure their commitment and would help insure that any preventive approaches developed would address the causes of the problem in a way that the fire service would see as valid and acceptable.

The population for the focus group study consisted of the same 14 fire departments that participated in the present study. In all, 39 individuals participated in the focus group study. Regardless of whether an individual (a) was a fire chief or one of the non-management personnel, (b) exercised or not, or (c) had incurred a compensated lost-time injury or not, there was agreement on a number of issues. Getting injured as a firefighter is inevitable, even though the injury may not result in time lost from the job. The person, workplace, and uncontrollable situational factors identified in the focus group study that have relevance for the present study include: (a) person factors such as physical fitness, anthropometric dimensions, history of musculoskeletal injury, age, gender, and experience; (b) workplace factors such as job tasks (e.g., lifting, bending, twisting), equipment, and the tradition within a given fire department about how to perform selected EMS job tasks; and (c) uncontrollable situational factors such as the EMS working situation (e.g., confined spaces or steep or winding staircases).

SPECIFIC AIMS

The objectives of the present study were to describe the Emergency Medical Service (EMS) tasks that place firefighter/paramedics (FF/Ps) at risk of musculoskeletal injury and to hypothesize ways to reduce the injury potential of those tasks. The ultimate goal of our long-term research program is the development of a series of comprehensive preventive interventions that integrate both health promotion and hazard control approaches. Quantifying the biomechanical parameters of FF/P tasks and understanding the variability that exists within the tasks is a prerequisite to the development of a sound, integrated prevention approach to reducing the severity and frequency of musculoskeletal injuries. The specific aims of the study were the following:

1. Identify (a) the physically strenuous EMS tasks most frequently performed by firefighter/paramedics, and (b) the contexts in which those tasks occur.

2. Quantify via task analyses the trunk motion parameters (range of motion, velocity, and acceleration) and the workplace parameters (work heights, reach distances, applied forces, and subtask frequencies) that are encountered in the most frequently performed, physically strenuous EMS tasks

3. Hypothesize ways to reduce musculoskeletal stressors in the identified EMS tasks. These hypothesized modifications would encompass the redesign of equipment and of methods of task accomplishment. The hypothesized modifications should be such that their validity can be tested in subsequent laboratory studies.

METHOD AND RESULTS

There were four distinct phases to this study, with each phase building upon the previous one. To facilitate reader understanding, each phase is reviewed separately, in turn. A separate Method Section and a separate Results Section are provided for each phase.

Phase 1 -- Task Identification

Method: Structured Interviews

Approach

In order to accurately identify the most frequently performed, physically strenuous tasks carried out during emergency medical service (EMS) activities, we wanted to interview the personnel who actually carry out those EMS tasks.

Subjects

We asked the fire chiefs of 14 participating suburban fire departments to identify the categories of line-duty personnel that regularly participated in the physical work of extricating or moving victims during EMS runs. To create the population list

from which to draw a sample of such personnel for the mailed survey, we asked the fire departments to provide us with the names of all personnel in those job categories. [We learned that personnel with a variety of job titles carry out EMS tasks and that, in some fire departments, personnel rotate in and out of the positions responsible for EMS tasks. Therefore, we included all relevant job titles and position rankings as we recruited participants for both the interview and survey phases of the study.] Although the population of firefighter/paramedics (FF/Ps) employed by the participating fire departments is primarily White male, we asked fire departments to indicate the gender and racial/ethnic category for each person they listed so that we could include female and minority FF/Ps to the extent possible. The 29 interviews conducted included I Black male, I Asian male, and 3 White females. The remaining 24 participants were White males.

The 29 interviews were conducted with personnel from 8 of the 14 participating fire departments. The 8 fire departments included varied in terms of the age, design, and density of the residential, commercial, and industrial buildings in their service territory. The fire departments also varied in size, economic resources, and staffing schemes (e.g., union versus non-union; full-time versus paid-on-call). We concluded the Interviewing Phase after the 29th interview, because we had achieved redundancy in the information being generated by the interviewees. Participation in the interviews was voluntary. Most of the interviewees were eager to describe and demonstrate the nature of their EMS tasks and explain what made them physically challenging. Most of the interviewees reported that they found the interview process to be a rewarding experience.

Procedures

Fire departments were approached one at a time for the purpose of recruiting personnel to be interviewed. A letter was sent to all personnel in the target fire department who had been listed as appropriate for inclusion in the study. The letter indicated the purpose of the study and the nature of the interview process. The letter explained that a researcher would be calling to speak to personnel about voluntary participation. The calls made to recruit personnel for the interviews included a set of screening questions to insure that the personnel interviewed would be those who did frequently perform EMS activities that they considered to be strenuous.

Participants were interviewed one at a time at their firehouse, with interviews lasting up to one hour. The interviews were audio/videotaped for review by the other members of the research team. Videotaping was used to capture detailed task descriptions and demonstrations of postures. These tapes provided the research team with initial information about the types of tasks that might need to be simulated. Thus, it was possible to begin the planning necessary to locate a suitable physical facility and to secure all the necessary equipment for creating the task simulations in which the actual biomechanical stresses would be measured. In order to test and refine the interview format, 5 pilot interviews were conducted with personnel from a fire department that resembled (but was not one of) the 14 fire departments involved in the full study.

Instrument

The following open-ended questions were used to guide the interviews:

- Which EMS/rescue tasks are both strenuous and frequently performed? (Suggested criteria for "strenuous" included subsequent fatigue or soreness.)
- Describe the kinds of runs on which these tasks occur. How often does the fire department make such runs? How often do you participate in them? What are the job titles of personnel that perform these tasks?
- Describe the physical settings in which you perform these tasks.
- What is it about these tasks that makes them physically strenuous?
- What kind of equipment is used in performing these tasks?
- Most of these tasks involve more than one person. What are the different roles that personnel perform while completing these tasks?
- Describe and demonstrate the movements and postures associated with each of the roles involved in performing each of these tasks.
- Out of the physical postures you go through to perform these frequent and strenuous tasks, which are the most strenuous postures?
- What are the sources of strenuousness in performing this particular task (e.g., gross weight lifted versus awkwardness of posture)?
- What is the type of exertion encountered in this particular task (e.g., burst of effort versus sustained effort)?
- What are the key muscles and joints involved in performing this particular task?
- What is the duration of maximal exertion in this particular task?
- Have you experienced any fatigue, soreness, or injury as a result of performing this particular task? If so, name the affected muscles and joints.
- How would you rank the strenuousness of this particular task compared to the other tasks you have described as strenuous?
- Do you have any immediate suggestions for making these tasks less strenuous?

Results of the Structured Interviews

The hand-written notes of the interviewer, the audiotapes, and the videotapes were used by the research team in the analysis. Frequency counts were compiled for the list of tasks mentioned in the interview . A detailed description was written of each of the top 11 tasks mentioned. The description included details of the roles performed in each task. This information was used in the survey phase of the study.

Phase 2 -- Task Confirmation

Method: Quantitative Task Survey

Approach

Based upon the information obtained from the 29 interviews, the researchers drafted a survey questionnaire to obtain data from the population of firefighter/paramedics (FF/Ps) employed by the 14 fire departments. Data was sought about the frequency of performance and the physical strenuousness of the identified emergency medical service (EMS) tasks.

Subjects

The main survey was a census (i.e., a 100% sample) of the population of all FF/Ps in the 14 fire departments who had previously been identified as regularly performing EMS tasks. A packet containing the questionnaire and a postage-paid, pre-addressed envelope for returning the questionnaire directly to the SRL was sent to each of the 518 FF/Ps. (The 24 who had been used in the pilot study were excluded from the main survey.) A total of 374 usable questionnaires were returned for a mailed survey completion rate of 72%. (This is an excellent completion rate.)

Survey Instrument

The draft questionnaire was reviewed by the Questionnaire Review Committee (QRC) of the University of Illinois Survey Research Laboratory (SRL), with whom we contracted to conduct the survey fieldwork. A pilot test was conducted with 24 FF/Ps to evaluate the appropriateness of the instrument and the survey procedures. Of the 24 pilot surveys distributed, 19 were returned, yielding a completion rate of 79%. Because the questionnaire was solidly based upon the interview data, no changes to the EMS task list were required. Based upon the pilot study data and feedback from the QRC, the questionnaire response format was slightly revised and minor changes to the coding procedures were made. The questionnaire was then finalized and printed in an easy-to-use booklet format (see Appendix A).

The questionnaire asked the FF/Ps to rate 11 EMS tasks in terms of frequency of performance and physical strenuousness. The 11 tasks, derived from the interviews, are listed in the survey booklet (Appendix A). For each task, the FF/Ps were asked to provide ratings for each of two separate jobs that were described as being part of the task. These jobs describe how the FF/P is maneuvering the patient or piece of equipment. For example, Task 6 is transporting a patient on a backboard down a straight line of steps while being in the higher position walking forward (Job 1) or being in the lower position walking backward (Job 2). The questionnaire also asked for age category, years of relevant work experience, and whether or not the FF/P was currently experiencing physical pain or had changed work methods because of physical pain.

Procedures

The packets for all the prospective participants at a particular fire department were sent in one bundle by express service to that fire department. To encourage response, the survey cover letter stated that, as a token of thanks to FF/Ps who completed the survey, a drawing would be held to give away three cash prizes (a $ 100 grand prize, a $75 second prize, and a $50 third prize). A letter was also sent to each fire chief urging him to encourage participation among his FF/Ps. Approximately 14 days after the initial mailing, a follow-up postcard was sent to all the FF/Ps and a follow-up letter to each chief. One month after the initial mailing, a second mailing of questionnaires was sent to those FF/Ps who had not yet responded. Questionnaires were numbered for tracking returns so that respondents could be entered in the drawing, but names were not associated with the information provided. This separation was implemented in order to maintain complete confidentiality.

Analysis

To assure the quality of the data coding, 52% (194) of the questionnaires were checked for accuracy by the SRL data reduction coordinator. Only five errors were found, yielding a very satisfactory error rate of .04%. As an additional quality check, frequencies were run on all the variables after half of the questionnaires had been coded to check for any unusual entries or skip problems. None was found.

Results of the Task Survey

In order to determine which of the 11 tasks should be selected for simulation in a controlled environment where ergonomic data could be gathered, the ratings for each task were plotted in two-dimensional space with one axis being frequency of performance and the other being strenuousness. Those tasks located in the upper right quadrant (high on both dimensions) were the tasks most likely to result in musculoskeletal injury production, and thus were selected for simulation. The four tasks in that quadrant were: Task 3 (Two workers transfer a patient from a bed to a stretcher using sheets); Task 6 (Two workers carry a patient on a backboard down a straight line of steps); Task 7 (Two workers carry a patient on a backboard around a curve in the stairway), and Task 8, (Two workers carry a patient in a stair chair down a straight line of steps. Also selected for simulation was one task that did not rate particularly high on strenuousness, but rated extremely high on frequency of performance because it occurs every time a patient is transported. This is Task 11 (Two workers transfer a patient from a stretcher to a hospital gurney using sheets). Once the Simulation Phase of the research was in progress, a sixth task was added to the set of simulations for some subject teams because of their use of a less-common piece of equipment -- a slat stretcher rather than a backboard -- for Tasks 6 and 7. This addition is described in the following section on the Simulation Phase of the project.

Phase 3: Postural Analysis

Method: Task Simulations

Approach

A set of six simulated emergency medical service (EMS) tasks was developed under the guidance of personnel from the consortium of MABAS III fire departments. The tasks identified via the survey conducted in Phase 2 were modeled such that the data collection requirements could be met while maintaining a close resemblance to the generic situations encountered by the firefighter/paramedics (FF/Ps). The six tasks selected for simulation included:

T1. Transferring a patient from a bed to a stretcher using a bedsheet (see Figures 1 and 2).

T2. Transferring a patient from a stretcher to a hospital gurney using a bedsheet (see Figure 3).

T3. Lifting and transporting a patient down a set of stairs and around a landing using a backboard (see Figures 4 and 5).

T4. Transporting a patient down a straight set of stairs using a stretcher (see Figure 6).

T5. Transporting a patient down a set of stairs and around a landing using a stairchair (see Figure 7).

T6. Transporting a patient down a set of stairs and around a landing using a slat-stretcher (see Figure 8). (This simulation was added at the simulation site after several teams of FF/Ps brought this piece of equipment, which was sometimes used by their fire departments.)

Tasks T3, T4, and T5 each contained a different combination of components. The components (subtasks) include:

S1. *Initial lift:* lift the backboard from the floor [see Figure 4(a)].

S2. *Initiate stair descent:* forward worker begins descending the stairs [see Figure 6(a)].

S3. *Mid-stair carry:* carry the victim down the straight portion of the stairs after both workers have begun descending the stairs [see Figure 6(b)].

S4. *Around-the-landing:* maneuver the backboard through the 90-degree turn and cramped space associated with a landing (see Figure 5).

Task T3 included all four of these task components. Task 4 included only components S2 and S3. Task T5 included components S2, S3, and S4. When the stretcher and stairchair were used (Tasks T4 and T5), the initial lift occurred at the

same time as the stair descent was initiated. Therefore, initial lift was not analyzed separately for Tasks T4 and T5.

Within each task there were two roles. (In the survey, the two roles were referred to as "Job 1" and "Job 2." In this report, the term "role" will be used in place of the terms "Job 1" and Job 2." Also, in the survey, the injured person being handled by the FF/Ps was referred to at the "patient." In this report, the term "victim" will be used in place of the term "patient.") For example, in the task of transferring a victim from a bed to a stretcher (Task T1), the following roles were identified in the initial interviews and validated by the survey as being strenuous and occurring frequently:

Role 1: Kneeling or standing on the bed and assisting the transfer of the victim by lifting the underlying bedsheet.

Role 2: Standing on the far side of the stretcher and pulling/sliding the victim toward yourself using the underlying bedsheet.

(See Figures 1 and 2. Also, see Page 6 of the Fire Service Survey. The Survey is enclosed as Appendix A.)

Subjects

Ten teams, each consisting of two experienced FF/Ps, were recruited from seven of the suburban fire departments participating in this study. The 20 volunteers, 17 male and 3 female, had been cross-trained as both firefighters and paramedics. Eighteen of the 20 worked full time for their respective fire departments. Two individuals came from a paid-on-call fire department. The mean height and weight of these individuals was 179 cm (range: 160-193 cm) and 87 kg (range: 57-118 kg), respectively. Each team's participation ranged from two to two-and-a-half hours. Prior to participating, the FF/Ps were briefed as to the tasks they would be asked to perform, and they signed an informed-consent form.

Apparatus/Environment

Data collection requirements included (a) an open stairway for videotaping, (b) a 90-degree (or greater) turn near the bottom of the stairs, followed by additional steps [the turn is equivalent to a landing], (c) an open staging area at the top of the stairs with adequate space for videotaping, and (d) open space in which to simulate the bed-to-stretcher-transfer and stretcher-to-gurney-transfer tasks. Through the cooperation of Fire Chiefs on our Advisory Board, we gained access to a moth-balled Naval Base building that suited our needs perfectly.

The stairway at the simulation site was considerably wider than that found in a typical residence in this part of the country. A rope was used to create an artificial "wall" one meter from the railing on the open side of the stairs. The rope was tied such that it was approximately one meter above the stairs and did not present a trip hazard. Each step had an 18 cm rise and a 30.5 cm run. In all, there were 19 steps including the landing, which required a 90-degree turn.

A conventional double bed, 193 cm long, 152 cm wide, and 53 cm high, was used to simulate the bed-to-stretcher-transfer task. The stretcher-to-gurney-transfer task was simulated by transferring the victim-dummy from one stretcher to another while the stretchers were in their raised positions (92 cm from the floor).

The victim was simulated by a dummy used for practice by one of the local fire departments. The weight of the victim-dummy was 471 N (48 kg). This weight is similar to that of a small female victim. While this weight is not representative of the entire population, we were continually reminded that heavier victims are typically handled by more than two workers. Moreover, to prevent fatigue we had to balance the weight carried against the number of carries we required of workers during our testing protocol.

Each team of FF/Ps brought their own equipment to use during the testing. This included a stretcher, a backboard, a stairchair, and straps necessary to secure the dummy to these transport tools. The variation in the weight of the backboards across departments, 62 to 71 N (mean = 69 N), largely depended upon how many straps were attached to the board. Stretchers varied between 303 and 401 N (mean = 368 N). Stairchairs showed the most variation across fire departments. Weights ranged between 80 and 107 N (mean = 94 N). The height of the chairs ranged between 94 and 137 cm. The handle height varied between 82 and 130 cm. It should be noted that approximately half of the FF/Ps elected not to use the handles on the stairchair during the testing procedure. Instead, they grasped the chair at the top of the seat-back. Two teams performed lifts with a slat-stretcher which weighed 71 N.

The two teams using the slat-stretcher indicated that they would never transport a victim down a flight of stairs using a conventional stretcher. This piece of equipment weighs the same as a backboard and is constructed out of canvas. It has wood strips, two meters in length, sewn into the fabric. This provides the slat-stretcher with longitudinal stiffness and lateral flexibility. The fabric handles sewn into the canvas allow the FF/Ps to carry the slat-stretcher with one hand. This frees their other hand to hold the banister during stair descent, possibly preventing a catastrophic fall. Moreover, the slat-stretcher affords the leader the advantage of walking forward down the steps.

Four video cameras were positioned to provide the best orthogonal views to the sagittal and frontal planes of the team of subjects. Trunk positions were determined with the Lumbar Motion Monitor (LMM) manufactured by Chattanooga Group, Inc. (Chattanooga, TN). This device measures the motion in the lumbar and thoracic sections of spine. Connections between the LMMs and the computers used for data collection were made through either a long wire or a radio link.

Procedures

Upon arrival, each member of a fire department team was instrumented with a LMM. The radio transmitter was provided to the LMM of the team member who volunteered to take on the transport tasks descending the stairs (walking backwards while carrying the victim). Strips of masking tape were placed over the ankles, the lateral side of each knee, the greater trochanters, the acromium processes, the mid-

lines of the elbows, and the mid-points of the wrist breadth dimensions. These strips were used in quantifying body postures from the videotapes.

The data collection started with the bed-to-stretcher-transfer task, followed by the stretcher-to-gurney-transfer task, and concluded with the three stair-descent tasks. The sequence of the stair-descent tasks -- with the stretcher, stairchair, and backboard -- was randomized for each team. Each task was repeated three times. Two teams indicated that they would never transport a victim down the stairs using a conventional stretcher. Instead, these teams frequently used the slat-stretcher, described earlier. Therefore, for one of these teams the slat-stretcher was substituted for the conventional stretcher. Data for this team was analyzed separately. The second team familiar with the slat-stretcher volunteered to perform extra trials so that more data could be obtained with this piece of equipment. Teams were allowed to select their own method for completing the task so long as the roles were consistent with those identified via the survey. One observed variation consisted of standing rather than kneeling on the bed during the bed-to-stretcher-transfer task. Another variation was that different FF/Ps used different arm postures as they descended the stairs backwards carrying a particular transport device (e.g., stretcher, backboard, or stairchair).

Hand forces were measured using a hand-held dynamometer (Wagner Instruments, Model FDV 100). For the bed-to-stretcher-transfer task and the stretcher-to-gurney-transfer task, the peak dynamometer readings were obtained as the force was slowly increased to overcome the frictional forces. Since the hand forces were not evenly distributed between the two roles in the victim transport tasks, hand forces were determined for each role. Once the distribution of forces was known for the backboard and stretcher, these forces were adjusted to accommodate the variations in equipment across teams.

Task Analysis Process

The tasks were broken down by task component, as shown in Table 2. Further, each task component included the two roles identified from the interviews and surveys. The videotapes were reviewed to obtain bi-planer postural data for the shoulders, and sagittal plane motion for all articulations except the torso. The torso postural data were obtained from the LMMs. For most task components, the reported postures were obtained from the most physically strenuous point in the performance of that task component. For example, in the transport-down-stairs-with-backboard task, the postures were analyzed as the subjects made the "initial lift" of the backboard from the floor [see Figure 4(a)]. In some of the transport task components (e.g., "mid-stair carry"), the trunk and arm postures were essentially static, thereby allowing the postures to be analyzed when the camera view was optimized. However, the averaged leg postures shown in the following section were more affected by the decision on where to freeze-frame the videotape for analysis.

Once the postural data were obtained from all the teams, those data were averaged across those teams that employed similar work methods. Where method variations could be identified, those subgroups were averaged separately. It should be noted, however, that there were typically a small number of observations in these subgroups (n = 1-3). Averaged data were used to construct figures for the postural

analysis. The figures were scaled using the average anthropometry presented by Marras and Kim (1993) as well as values obtained from other published sources (Webb Associates, 1978).

Results of Task Simulations and Postural Analyses

Bed-to-Stretcher-Transfer Task

Figures 1 and 2 show the two roles defined for the bed-to-stretcher-transfer task. One FF/P stood on the floor and reached across the stretcher (stretcher width = 56 cm) to grasp the sheet and pull the victim onto the stretcher. The other FF/P assisted by kneeling or standing on the bed and lifting the victim with the sheet.

For the individual in the pulling role, the measured applied force was 268 N. This force, while having a strong horizontal component, must also contain enough of a vertical component to assist the victim over the stretcher-bed interface and reduce the frictional force. This task required the pulling FF/P to work in a stooped posture at the point when the greatest force would be exerted. Trunk flexion angles averaged 54 degrees (sd = 20) at the initiation of the motion. The lower extremities were also used to prevent the stretcher from moving, thereby limiting the postures that could have been adopted during the patient transfer.

The FF/P positioned on the bed provided a lifting force to reduce the frictional force encountered by his or her partner and to assist the victim over the bed/stretcher interface. Kneeling on the bed, while providing stability to the FF/P's initial posture, did not allow for easy movement. As a result, most of these individuals completed the transfer with outstretched arms and significant forward spine flexion (49 degrees, sd = 18). This posture would create a large moment (torque) acting on the spine. Three FF/Ps performed the simulation by standing on the bed. By standing, the FF/Ps could potentially exert more of the lifting force with their legs while maintaining mobility, and hence achieve shorter reach distances at the completion of the transfer. However, the transfer task was still initiated with a significant amount of forward bending as the FF/P typically grasped the sheet near the victim. Figure 2 shows some representative observations obtained as FF/Ps in the bed role completed the two methods. Note the difference in the reach distance. While standing appears beneficial in a static analysis, the FF/P's stability may be compromised due to the mattress underfoot. Time should be taken to achieve a stable stance before the initial lift.

Stretcher-to-Gurney-Transfer Task

This task was the least strenuous of the tasks simulated. However, it is performed on nearly every EMS run. This task requires the victim to be lifted or dragged from one surface to the other (Figure 3). The FF/P in the "pull" role lifts and/or drags the victim toward the gurney and toward his or her torso. The FF/P in the "push" role primarily lifts the victim to reduce the frictional force.

In most cases, the exertion was coordinated by the two FF/Ps through a synchronizing count. This is particularly important because it reduces the likelihood that one individual will bear more of the load than s/he had anticipated. The forces measured with the dynamometer as the 467 N dummy was moved were 248 N for the

FF/P pulling and 258 N for the FF/P lifting. These were the peak force values captured during a slow transfer. Faster transfers would require that larger forces be applied. Likewise, a heavier patient would require larger forces. FF/Ps reported during interviews that the availability of assistance from hospital staff cannot be relied upon. However, if hospital staff happen to be available, they will generally assist in patient transfer.

The postures shown in Figure 3 represent the average postures found at the point the transfer is initiated. For the pull role, the trunk flexion derived from pelvic rotation and spine flexion was 22 degrees (sd = 8.7) and the arms were outstretched. In the push role, the initial posture was even slightly more stooped. This enabled the pushing FF/P to lift more with his/her back rather than relying on arm strength and shoulder strength.

The LMM detected lateral bending in some individuals in the pull role at the end of the exertion. This supplemental motion occurred as the lower extremities of the victim were transferred onto the hospital gurney. Usually this was not accompanied by any foot movement on the part of the FF/Ps. Firefighter/paramedics should be encouraged to align themselves with the lower extremities prior to this component of the lifting task, thereby eliminating the trunk lateral-bending component.

Transport-Down-Stairs-with-Backboard Task

This task comprises a series of task components. First, the victim on the backboard is lifted from the floor to waist level ("initial lift"). Next, after a short carry, the FF/Ps reach the stairs and "initiate stair descent". Once both the FF/Ps are on the stairs, the "mid-stair carry" subtask begins and continues until the landing is reached. At this point, postures change as the backboard is carried through the 90-degree turn in the stairs which we call the landing ("around the landing"). The two roles in the stair transport tasks have been defined as the "leader" and "follower" roles. The leader lifts the foot of the backboard (the end of the backboard where the victim's feet are placed) and carries the board while walking backward down the stairs. The follower lifts the head of the backboard (the end of the board where the victim's head is placed) and carries the board while walking forward down the stairs.

Figure 4(a) shows the most extreme postures, averaged across the 10 teams, observed during the initial lift. The FF/Ps in both roles approached the task by straddling their end of the backboard. The trunk was essentially maximally flexed, the elbows were essentially fully extended, and the knees were flexed approximately 90 degrees (sd = 21). The force distribution between the two FF/Ps indicates that the center of mass of the victim was closer to the FF/P at the head of the backboard.

Figures 4(b) and 4(c) show the initial sagittal plane postures as each FF/P started down the stairs. In the leader role, the trunk posture was essentially upright. The elbows tended to be flexed to maintain the victim in a more horizontal orientation and to provide clearance for the legs as the leader was beginning to step backwards down the stairs. The first couple of steps taken were accompanied by approximately 10 degrees of side bending (sd = 3) and 11 degrees (sd = 1) of twisting motion within the torso. This motion primarily occurred as the leader turned to view the stairs below him. In the follower, these motions were reduced to approximately 5-6 degrees (sd =

2) in each direction. The follower's elbows were more extended than the leader's and the trunk was more upright. For both roles, the trunk and upper extremity postures were essentially unchanged throughout the descent of the remaining stairs. Relative to the follower, the leader continued to show slightly more twisting and side bending of the torso, as s/he made repeated visual checks of the stairs.

The landing required a 90-degree turn. The still images from the video, seen Figures 5(a) and 5(b), show that the trunk was typically upright to hyper-extended, twisted, and laterally bent as the leader backed around the corner. Most of the FF/Ps in this role had their elbows flexed an average of 73 degrees (0 degrees being a straight arm) (sd = 29). Two individuals elected to carry the backboard in a raised position with the elbows flexed approximately 120 degrees, thereby bringing the board up to near chin level. This variation in method may have reduced the horizontal distance from the hands to the spine, and hence reduced the forward bending moment acting on the spine. Unfortunately, LMM data was only available for one of these individuals. It showed greater twisting and lateral bending, 17 and 19 degrees respectively, than found with the lower arm posture (12 degrees twisting (sd = 4) and 7 degrees of lateral bending (sd = 2). This occurred because, as the FF/Ps proceeded through the landing with the lower arm posture, they could rotate their shoulders to shift the board laterally rather than use trunk motion. Without the arms raised, the effectiveness of the shoulder rotation would be greatly diminished.

Transport-Down-Stairs-with-Stretcher Task

For purposes of analysis, this task was broken into two task components: (a) "initiate stair descent" [see Figure 6(a)] as the stretcher was rolled off the top of the stairs, and (b) "mid-stair carry" [see Figure 6(b)], the actual activity of descending the stairs. Discussions with the participating FF/Ps confirmed survey results which indicated that, if the rescue required lateral shifts in addition to transport down a straight flight of stairs, a stretcher would not be used. Therefore, the "around-the-landing" component of the transport-down-stairs-with-stretcher task was not simulated.

The individual in the leader role of the first task component [see Figure 6(a)] "initiated stair descent" from a position two-to-three stairs below the plane of the floor on which the stretcher was standing. This lowered position resulted in only an average of 24 degrees (sd = 16) of trunk flexion during the initial lift. There were 9 degrees of twisting (sd = 1) and lateral bending (sd = 4) motion measured by the LMM during the lift. This occurred primarily as the FF/P reached for the stretcher or when a visual check of the stairs was performed. The leader lifted 48 percent of the combined weight of the victim and the stretcher. This weight averaged 404 N across the stretchers used.

Relative to the leader, the FF/P in the follower role showed more forward bending of the spine as the stretcher was lifted (49 degrees; sd = 29). Generally, there was very little twisting or lateral bending of the torso accompanying the follower's lift. The torso flexion, combined with moderate degree of shoulder flexion (42 degrees; sd = 35) and small amount of elbow flexion (20 degrees; sd = 19), allowed the hands to be positioned just in front of the knees at the point the stretcher was lifted. The follower lifted 52 percent of the combined weight of the stretcher and the victim, which was 431 N.

Once on the stairs, the postures of both FF/Ps were much more erect [see Figure 6(b). By extending the shoulders 17 degrees (sd = 11) and flexing the elbows 84 degrees (sd = 6), the leader raised the stretcher away from his or her legs and held it close to the torso. Alternatively, the stretcher was carried by the leader in an arms-raised posture -- see Figure 6(d). This lift was initiated with the hands near shoulder level, through a combination of shoulder and elbow flexion, and with greater forward bending of the torso (mean = 36 degrees) [see Figure 6(c)]. Once lifted, the stretcher remained in a more horizontal orientation as it was carried down the stairs. The leader's hands were approximately the same distance horizontally from the spine as with the conventional method. Thus, the moment introduced by the 467 N was equivalent once the stretcher was lifted. However, the lifting process would increase the moment placed on the spine, because of the additional forward bending.

Transport-Down-Stairs-with-Stairchair Task

Three components of this task were studied: (a) "initiate stair descent," (b) "mid-stair carry," and (c) "around-the-landing." [See Figures 7(a) and 7(b)]. The total weight of stairchair and victim used in this test averaged 555 N. Of this, the leader and the follower carried 38% and 62% of the load, respectively.

At the top of the stairs, the chair was typically rolled to a position near the edge of the top step and tilted prior to lifting. The leader bent forward an average of 34 degrees (sd = 15) during the initial lift -- see Figure 7(a). The handle locations were more varied on the stairchairs than on any other type of equipment. Typically, the handles were in close proximity to the frame. However, on one model the handles for the leader extended approximately 30 cm to provide separation between the FF/P and the victim's lower extremities. Often the FF/P's feet were vertically separated by one stair as the chair was lifted. This allowed some of the lifting force to be generated by the lower extremities and helped the leader to maintain fore-aft stability. The follower's role changed at this point from one primarily of pushing to one of lifting. The torso was flexed slightly forward (15 degrees; sd = 16) and the elbows were flexed about 22 degrees (sd = 17). This nearly-straight arm posture was maintained by the follower during the "mid-stair carry" -- see Figure 7(b).

As the carry progressed, the trunk postures tended to be erect in both roles. The leader's elbows were flexed approximately 100 degrees (sd = 18), whereas the follower's elbows were flexed only 28 degrees (sd = 28). Thus, even though the leader carried less of the combined victim and chair weight, the flexed-arm posture increased the moment acting on the spine. Similarly, the compression predicted with the Three-Dimensional Static Strength Prediction Model (3DSSPM), developed by the University of Michigan, was 13 percent larger (Lavender et al., 1997). These postures were maintain through the landing to the point at which the stairchair was placed on the ground. As the chair was lowered, the leader's trunk flexed 31 degrees (sd = 17), whereas the higher handles on the back of the chair only required 10 degrees (sd = 10) of forward bending by follower.

Transport-Down-Stairs-with-Slat-Stretcher Task

Figures 8(a) and 8(b) show the "initial lift" of the slat-stretcher from the floor and the "mid-stair carry", respectively. The leader is using the one-handed method of

carrying. The "initial lift" is very similar to that found when lifting a backboard, although with slightly less forward bending at the point that the load is experienced by the FF/Ps. As with the initial lift using the backboard, the stretcher and victim are straddled so that the legs can be used to provide some of the lifting force, and so that the hands can be kept close to the torso in order to minimize the resulting moment placed on the spine.

The advantage of the slat-stretcher is that, depending upon the weight of the victim and the strength of the FF/P, it can be carried down the stairs with the leader facing forward -- see Figure 8(b). Generally, the posture was upright with a small degree of shoulder extension in the arm supporting the stretcher. However, it should be noted that this method was only observed in one FF/P. The leader of the second team that used the slat-stretcher descended the stairs backwards in a manner that was very similar to that observed with the backboard. While carrying the slat-stretcher with one hand may reduce the safety risk, the strength capacity of the leader's supporting upper extremity and contra-lateral back muscles may be exceeded with this method, potentially leading to a muscle-strain type of injury.

Phase 4: Biomechanical Task Analyses

Method

Approach

Data obtained from the simulation phase of the study were used in this last phase.

Biomechanical Task Analyses

The postural data were extracted from the videotapes using the cameras with the most orthogonal view for the given task component. Body segment orientations were expressed in terms of the coordinate system specified within the University of Michigan's Three-Dimensional Static Strength Prediction Model (hereinafter referred to as 3DSSPM). The three-dimensional trunk postures were obtained from the Lumbar Motion Monitor (LMM). This required the transformation of the trunk flexion angle so that it would be consistent with the 3DSSPM system.

Each task component was modeled for each individual in the simulation using the 3DSSPM. Each FF/P's height and weight were entered into the Model. The Model was then scaled according to these anthropometric dimensions. The hand forces were assumed to be an even distribution of the forces measured with the dynamometer. Postures in the computer model were adjusted according to each subject's measured posture. The computer model used these data to compute the net static moment at each articulation. These moments were then compared with population strength data for each of the articulations to determine the percentage of the population with similar anthropometric characteristics that would be capable of performing the modeled exertion. Therefore, the Model yields the percentage of the population who can develop the estimated moments at each articulation (strength capacity) to perform each muscular exertion. Tasks in which strength becomes a

limiting factor should be considered as putting people at risk for overexertion type injuries (Chaffin, 1979).

Compression values were computed by the 3DSSPM software for the intervertebral disc between the fourth and fifth lumbar vertebrae using the 3D trunk model developed by Bean et al. (1988). Compression values were compared with the compression tolerance limits used by NIOSH (1981) in the initial version of the lifting guidelines.

The Trunk Motion Logistic Regression Model (LRM) developed by Marras et al. (1993) was used to quantify low-back-disorder (LBD) risk based upon the trunk motion and dynamometer data. This model uses the following five factors to determine the probability that the observed task is representative of a high-LBD-risk task: the lifting rate per hour, the average twisting velocity, the maximum load moment during the lift, the amount of forward (sagittal) bending during the lift, and the peak lateral bending velocity. The trunk motion data were obtained from the LMMs, the moment data were obtained by multiplying the dynamometer reading by the maximum horizontal reach distance, and the lifting rate was set to a value of 5 to represent the average lifting rate per hour.

Descriptive statistics were computed for each of the quantities calculated above to show the overall trends in the data. Strength capacities extracted from the 3DSSPM output were not normally distributed, so the median value has been presented to describe the central tendencies in these data. Mean values have been used for all other quantities. The probabilities obtained with the LRM, the strength percentages, and the compression estimates were compared across conditions (tasks, task components, methods, and roles) by using analyses of variance (ANOVAs) and the Mann-Whitney non-parametric tests.

Results of the Biomechanical Task Analyses

Bed-to-Stretcher-Transfer Task

Strength limitations were most apparent for the FF/Ps standing on the far side of the stretcher. The median values across the 10 FF/P's modeled indicated that only 71 percent of the population would have adequate back strength to perform the modeled task. However, only 17 percent of the population has enough strength in the shoulders to abduct the arms into the modeled posture (30 degrees of shoulder abduction). Lifting and pulling the 47 kg dummy onto the stretcher resulted in spine compression values at L4/L5 between 3700 N and 7600 N (mean = 5476 N). Therefore, all compression values observed during the performance of this task in the stretcher-side role exceeded the NIOSH Action Limit (AL) of 3434 N. Some values even exceeded the Maximum Permissible Limit (MPL) of 6377 N. Figure 9 shows that the spine compression values were significantly greater ($p<.001$) for the stretcher-side role as opposed to the bed-side role.

Strength in the upper extremities and the back were not limiting factors for the FF/Ps kneeling or standing on the bed. Spine compression values were 45 percent less (see Figure 9) while anterior shear forces were nearly 90 percent greater in the standing (stooped) posture compared with the kneeling posture.

The LRM indicated that the bed-to-stretcher-transfer task is a high-risk task with respect to low back disorders. The mean probability values, averaged for the FF/Ps on the stretcher and the bed sides of the transfer were 96 percent and 89 percent, respectively (see Figure 10). The primary factors responsible for these high probability values were: (a) the moment due to the extreme reach, and (b) the degree of forward bending. The greater reach on the stretcher side probably accounts for the significantly higher risk ($p<.01$) associated with this role. Moreover, both roles showed some moderately fast twisting motions (over 8 degrees/second), which also served to elevate these probabilities. The probability values, on average, were less (82%) in the FF/Ps who elected to stand as opposed to kneel on the bed (90%), although, due to the small sample size, this was not statistically tested. The difference was primarily due to faster twisting and side-bending motions in the kneeling posture.

Stretcher-to-Gurney-Transfer Task

Only 86% of the population would have adequate back strength to pull the victim off the stretcher and onto the gurney. This pulling role was significantly more demanding on the back and shoulder abduction strength than for the FF/P on the stretcher side ($p<.05$), with only 35% of the population having sufficient shoulder abduction strength to perform the pulling role in this task. Knee strength, however, was a limiting factor in the FF/P on the stretcher side during the transfer. Only 80 percent of the population would have adequate knee flexion (hamstring) strength to perform this function.

Estimated spine compression was 56% higher ($p<.001$) for the FF/P on the gurney side (3350 N) as compared to the stretcher side (2147 N) of the transfer (see Figure 9). On the other hand, anterior shear was over six times greater for the FF/P on the stretcher side (323 N) than for the FF/P on the gurney side (52 N) during the transfer ($p<.001$).

Probabilities generated by the LRM were 78% and 73% for the stretcher side and gurney side of this transfer task, respectively (see Figure 10). The primary factor in the Model driving these high probability values was the moment associated with the extended reach distances.

Transport-Down-Stairs-with-Backboard Task

This task and its components are illustrated in Figures 4(a), 4(b), and 4(c). The backboard transport task was broken into four components: (a) "initial lift" from the floor, (b) "initiate stair descent," (c) "mid-stairs carry," and (d) "around-the-landing." The starting height of the handles during the initial lift was between 2 and 5 cm. The resulting low-level lift was significantly more strenuous for the FF/P lifting the head of the backboard ($p<.05$). Only 92% of the population would have the back strength necessary to complete the lift at the head of the backboard with the 467 N victim-dummy. Figure 11 shows that the compression forces between the fourth and fifth lumbar vertebrae were also significantly greater ($p<.01$) for the FF/P at the head of the backboard (5224 N) as opposed to the foot of the backboard (3955 N). Similarly, the anterior shear was significantly greater ($p<.05$) when lifting the head of the backboard. The TMLRM output yielded a significantly higher mean probability value of 58% for the head of the backboard as opposed to 44% for the foot of the

backboard (see Figure 12). The primary factor distinguishing between these two roles was the weight lifted and the resulting moment that was generated about the spine (69 Nm at the head of the backboard versus 41 Nm at the foot of the backboard).

In the "initiate stair descent" component of this task, knee strength could be a limiting factor for up to 10% of the population, especially for a person in the "leader" role. Analysis of the median values indicated that the upper extremity strength requirements were not of significant concern. Spine compression values during this task component were much lower than during the "initial lift" (see Figure 11). The FF/P at the head of the backboard experienced an average of 2826 N of spine compression, whereas the FF/P at the foot of the backboard only experienced 2763 N of spine compression. This task component was of relatively low risk from the standpoint of the LRM (see Figure 12). The probability that this task component was representative of a high-risk task was only 26% for the role at the foot of the backboard and 27% for the role at the head of the backboard. While the moment contribution to the Model was greater at the head (supporting the upper body weight), FF/Ps in the "leader" role (descending the stairs backwards) displayed more rapid twisting motions as they turned to view the stairs below them.

Once the FF/Ps reached the "mid-stair carry" component of this task, the probability value increased slightly for the FF/P in the follower role to 33%, primarily due to an increase in the trunk's twisting velocity. The probability value for the leader remained essentially unchanged (Figure 12). For either role, upper extremity strength was not a limiting factor. However, according to the 3DSSPM output, knee strength could potentially be a limiting factor for up to 14% of the population. On average, back strength was generally more of limiting factor for the leader than the follower role, although not significantly so. Spine compression values were relatively low, and were very similar for these two roles (2535 N for the leader, 2549 N for the follower).

In the "around-the-landing" component of this task, FF/Ps in the leader role showed two variations in arm postures which affected spine loading [see Figures 5(a) and 5(b)]. Most FF/Ps in the leader role (n = 8) continued through the landing carrying the backboard between waist and elbow level. Two leaders elected to raise the backboard to approximately chin level during this task component. There were no significant differences between the two roles with regard to joint strength requirements, nor was there any difference due to the method variation just described. Spine compression values did not differ significantly by role, but were on average larger, on average, than those experienced while in the "mid-stair carry" component of the task (mean = 3185 N across all FF/Ps observed -- see Figure 11). The probability values from the Logistic Regression Model associated with the "around-the-landing" component of this task are greater than the values for the "mid-stair carry" component (see Figure 12). However, the values mark this as a relatively low-risk task, relative to the other strenuous EMS tasks frequently performed by FF/Ps. Trunk motion data for FF/Ps who raised the board to chin level while in the role of leader during the "around-the-landing" component of this task were available from only one individual. But this one data point suggests that there was a considerably elevated risk as this task component was performed (see Figure 12).

Transport-Down-Stairs-with-Stretcher Task

This task is illustrated in Figures 6(a), 6(b), 6(c), and 6(d). Back strength becomes a limiting factor when a victim is transported down the stairs using a stretcher. Only half (53%) of the population would have adequate strength to carry a 467 N victim (weight of our victim dummy), on the stretcher, in the leader role. A smaller percentage of the population (41%) would have enough back strength to "initiate stair descent" carrying the stretcher in the raised position. This position was used by three of the FF/Ps performing this task component in the role of leader. Furthermore, in the more common, waist-level carrying position [see Figure 6(b)], under half (45%) of the population would have enough elbow-flexion strength to support the combined load of the stretcher and victim. Conversely, 99% of the population would have the elbow strength necessary to carry the stretcher in the raised position. This explains why, in part, the raised posture was selected. The raised posture reduces the moment acting at the elbow by reducing the horizontal distance between the grasping point on the stretcher and the elbow's axis of rotation. However, the raised posture tend to increase the shoulder adduction moment, thereby increasing the shoulder abduction strength requirements to the point that only 37% of the population would have adequate shoulder strength to use the raised posture in this task.

The back strength demands on the FF/P in the follower role during the "initiate stair descent" component of the task, while significantly lower ($p<.01$), were still quite high. Only 76% of the population would be able to perform this task component in the follower role. Associated with the high strength demands were large spine compression forces. These were 4500 N for the leader carrying the stretcher at waist level, and 5700 N for the leader carrying the stretcher at chin level (see Figure 11). Both values exceed the AL proposed by NIOSH. The compression for the follower was 4700 N, which was not significantly different from that for the leader carrying the stretcher at waist level. As the FF/Ps moved from the "initiate stair descent" component to the "mid-stair carry" component, the spine compression values declined: down to 3700 N for the waist level posture and 4000 N for the chin level posture. This reduction occurred at the same time as the reach distances were minimized and the trunk postures became more upright.

The probability values generated by the LRM were greatest for the FF/P in the leader role in the "initiate stair descent" component of this task (see Figure 12). An analysis of variance indicated a significant interaction effect between the task component and the role within that component ($p<.001$). In essence, the LBD risk indices for this task component were extremely high for FF/Ps in both the leader role (97%) and the follower role (85%) -- (see Figure 12).

Ninety-two percent of the population would have enough back strength to carry the stretcher down the stairs once the stairs have been initiated. Elbow strength could be problematic for up to 13% of the population performing in this capacity. In the leader's role, on the other hand, which was less demanding than the initial lift at the top of the stairs, back strength would still be problematic for 31% of the population when carrying the stretcher at waist level, and for 19% of the population when carrying the stretcher at chin level. Similar trends and trade-offs between elbow and

shoulder abduction strength exist across these method variations as found in the previous task component.

Transport-Down-Stairs-with-Stairchair Task

Initiating the stairs with the stairchair was significantly ($p<.05$) more demanding on the back for the leader as compared to the follower. Only 82% of the population would have adequate back strength to perform the leader's task, as opposed 91% who could likely perform the follower's task. In general, this task component was within the strength capacity of the upper extremities. Spine compression forces followed a similar pattern. The leader's spine compression was, on average, 37% greater than that experienced by the follower (see Figure 11).

An analysis of the variance in the outputs from the logistic regression model indicates that there were significant differences between the roles within this task ($p<.001$), and between components of the task ($p<.05$), but that these relationships did not change across task components ($p>.05$). The probabilities associated with the leader's role went from a maximum of 57% during the initial descent component, to 48% during the carry, and down to 37% as the landing was negotiated. The probabilities for the FF/P in the follower role were 32%, 32%, and 27% for the same sequence of task components, respectively (Figure 12).

Transport-Down-Stairs-with-Slat-Stretcher Task

Based on analysis of data from a very small sample ($n = 2$), only 83% of the population would have enough strength in their back to lift the head of the slat-stretcher. Once lifted, however, the handling of the slat-stretcher with the victim dummy (weight = 467 N) would be within the back and upper-extremity strength capacities for most of the population until a landing had to be negotiated. While 92% of the population would have adequate back strength, only 88%, 81%, and 82% of the population would have the necessary shoulder-abduction strength, elbow strength, and knee-extension strength, respectively, to perform the follower role in the landing. Spine compression values were relatively low except for the initial lift. However, this analysis was based on only two FF/Ps in each role.

The LRM indicated that use of the slat-stretcher resulted in similar probability values as those found when handling the backboard during the initial lift. However, the slat-stretcher values for the remaining task components compare favorably with those reported for the other transport tasks.

DISCUSSION

This study has described the postures adopted and the forces applied by FF/Ps as they simulated frequently-performed strenuous work tasks. Studies have shown that in both nursing and fire service settings, patient handling and transport tasks are physically demanding and often tax the musculoskeletal system to its limit (Gagnon et al., 1986, 1987; Jensen, 1987). What makes it more challenging to design ergonomic improvements in the FF/P job is the variation that exists from one EMS work setting to the next (i.e., from one EMS run to the next). But when the EMS

tasks are broken down into components, there are several components that are common across most EMS runs. For example: (a) victims are often found in bed, (b) victims must often be transported down stairways, (c) stairways often include landings and a corresponding change in direction, and (d) most EMS runs terminate with the transfer of the victim from the stretcher to a gurney at the hospital. Thus, we believe that risk factors can be identified and effective injury control measures can be developed by breaking frequently-performed strenuous EMS tasks down into their component parts.

During the simulations, FF/Ps were permitted to vary the method by which the task was performed if the variation was consistent with the task description used in the survey phase of this study. The only exception to this policy occurred when two teams offered to demonstrate the slat-stretchers that they regularly used.

Most of the variations in method during the transport tasks with the backboard and stretcher involved the leader raising the transport device to shoulder level, instead of carrying it at waist level. The raised position permitted the victim to be carried in a more horizontal orientation on the stairs. When the backboard was being carried around a 90-degree turn (landing), the raised position did allow tall leaders to guide the backboard over the railing on the inside of the turn. For leaders not tall enough to lift the backboard over the railing, the raised backboard position simply led to increased side bending and twisting in the torso. The raised position may reduce the static load on the elbow-flexing muscles during the carry down the straight portion of the stairs. On the other hand, it may reduce the stability of the leader's stance, because of the elevation of the victim's center of mass relative to that of the leader.

The other notable method variation that occurred during the simulation was where the FF/P on the bed during the bed-to-stretcher transfer elected to stand on the bed rather than kneel. Biomechanically, this puts the FF/P in a much stronger position. The muscles that extend the knees are now capable of exerting force and the muscles that extend the hips and spine are at a stronger position within their range of motion. This method also allows the lifter greater mobility and lessens the need for hand positions far from the torso at the completion of the lift. Further analysis is needed, however, before recommending this method to the fire service. The optimal hand position on the sheet relative to the victim must be determined so that the force the FF/P can exert to grip and lift is maximized while the risk of musculoskeletal injury is minimized.

In terms of the biomechanical analyses, this study has documented the muscular strength capacities, the mechanical loading of the spine, and the relative risk of low back disorder associated with several EMS task identified by FF/Ps as being frequently performed and strenuous. It was shown that a significant proportion of the population would not have the strength required to perform a number of these tasks. This should be cause for concern, given the relatively low weight of the simulation dummy handled in this study. Clearly, with heavier victims even a smaller percentage of the population would have the strength capacity to perform these relatively frequent EMS tasks.

Likewise, these same tasks were shown to have components similar to those found in jobs with a high historical risk of low back disorder. Large moments are

common to all the most strenuous task components. These moments are introduced by (a) heavy loads, as in the case of the transporting the victim down stairs on a stretcher, or (b) extended reaches, as in the victim transfer tasks. Most of the particularly strenuous task components also included substantial forward bending of the torso (e.g., initial lifts or the initiation of the stairs).

The results suggest that, whenever possible, personnel should avoid using a stretcher to transport victims down stairs. When a stretcher must be used, additional personnel should be recruited to carry out the task (e.g., use four FF/Ps instead of two). This will intervention will reduce the weight borne -- and the moment experienced -- by each FF/P.

Overall, the data from tasks involving the stairchair suggest that it poses less of a hazard when transporting victims down stairs than does the stretcher. The entry for the initiation of the stairs showed only a 56 percent probability. This indicates that the stairchair should be recommended for use when transporting victims down stairs, if their medical condition permits.

The backboard is an acceptable alternative to the stairchair and the stretcher for carrying victims down stairs, especially if there are no sharp turns in the descent. In the present study, the initial lift was modeled as being from the floor. This lift is strenuous, and thus is risky. If the degree of lift can be reduced -- as when the victim is already lying on an accessible, elevated surface (like a bed), then risk in using the backboard is reduced. Carrying the backboard through the landing could be facilitated through some interventions in backboard design. Most backboards are fixed in length and are made long enough to accommodate the taller people in the population. If the board were adjustable in length, then the board could be made shorter when shorter victims were carried. The reduction in length would facilitate maneuvering in confined spaces, and when moving through sharp turns in hallways and stairways. A waist harness system could be developed that would allow the board to be carried in a hands-free mode. By transferring the weight directly to the pelvis the spine remains unloaded during the transport task.

An obstacle to assessing the ergonomic risk among fire service personnel was our inability to systematically record the work of FF/Ps during actual EMS runs. Legal, ethical, and logistical considerations prevented our doing so. We need to develop a methodology whereby we could obtain realistic data in a systematic and efficient way in a in a controlled setting. That challenge was met. In the present study we demonstrated a useful methodology (i.e., a progression from interview to survey to simulation) for capturing reliable and valid data for assessing ergonomic risks among workers whose jobs cannot be systematically observed in field settings.

This analysis has indicated several areas in which design changes could be incorporated into future equipment. The patient transfer task from bed to stretcher and from stretcher to gurney would be facilitated by having a low friction interface available that bridges the gap between the two surfaces. By building flaps coated with a low friction surface into the equipment, the sliding of victims from one surface to another would be facilitated, and the need to actually lift the victim would be reduced.

The limited testing with the slat-stretcher was useful in that it really highlighted the obvious benefits of the leader walking down the stairs facing forward. Designers of emergency response equipment should consider the use of waist harness systems where backboards could be "clipped" in. This would have three principle benefits: First, the leader is facing forward looking at the steps. Second, the hands are free to hold the railing. Third, the weight of the victim is placed directly on the pelvis rather than the standard transmission through the arms and spine. Along these same lines a backboard with a pivot that allows up to 20 degrees of frontal plane motion at the hip level would facilitate transporting a victim through a landing on a set of stairs. While such a board would need a mechanism to prevent this motion should this region need to be rigid, in many situations this flexibility in the board would reduce the stress placed on the body as the board is jockeyed around corners. Likewise, developing a board that can be adjusted in length may relieve some of the same stresses at least when shorter victims are carried.

Limitations to the Present Study

There are three major limitations to the present study which need to be discussed. First, the weight of the victim dummy was relatively low compared to the average weight for an adult in the United States. We believe, however, that the victim-dummy weight was heavy enough for us to sample realistic working postures. We believe that the postures sampled are consistent with those that FF/Ps use when handling heavier victims.

A second limitation of the present study is that the biomechanical loading of the spine was computed with a static model, thereby resulting in low estimates of the true spine compression and shear forces experienced during some of the task components modeled. This means that the dynamic and inertial forces acting on the body segments were neglected in the present analyses. However, previous studies (e.g., Tsuang et al., 1992) suggest that the dynamic force contributions should have been relatively modest, given the combined weights of the victim dummy and the EMS equipment.

The third limitation pertains to the quality of the simulations. Ideally, these observations would be obtained under real emergency conditions. It is clear that this cannot be done without interfering with the quality of EMS service overcoming numerous legal and ethical obstacles. The simulations were developed under the guidance of an advisory panel of Fire Chiefs from MABAS Division III of the Illinois Mutual Aid Box Alarm System. Their expertise helped to ensure that the simulated tasks were representative of the typical EMS situations encountered by their personnel. Thus, we are confident that what we have learned from this study is applicable EMS tasks encountered in the real world.

CONCLUSION

Fire service workers must routinely handle very high loads when performing EMS tasks. The present study, by analyzing the postures and forces applied during frequently-performed strenuous EMS tasks, has indicated promising targets for injury control efforts. The fire service has often dealt with high loads on EMS runs by simply

using more personnel to make a particular lift or carry. However, the present study shows that there are plenty of opportunities for engineering changes to EMS equipment that could reduce musculoskeletal injuries.

The present study demonstrated a reliable and valid method for assessing ergonomic risk among workers whose tasks would be difficult to study during actual work operations. The study surveyed fire service personnel to learn which EMS tasks they find to be the most frequently-performed and strenuous ones. The study then determined the muscular strength requirements, the mechanical loadings of the spine, and the relative risks of low back disorder associated with components of those EMS tasks. The study found that strength limitations would prevent a significant proportion of the population from performing these tasks. This finding should be cause for concern, given the relatively low weight of the simulation dummy used in this study.

Finally, research team members and study participants hypothesized interventions to reduce the risk of musculoskeletal injury associated with EMS tasks. The next step for researchers and fire service personnel working on the injury problem is to test the interventions hypothesized in the course of this study.

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REFERENCES

Andersson, G. B. J. (1997). The epidemiology of spinal disorders. In J. W. Frymoyer (Ed.), The adult spine: Principles and practice, 2nd Edition (93-141). Philadelphia: Lippincott-Raven.

Andersson, G. B. J., Pope, M. H., Frymoyer, J. W., & Snook, S. (1991). Epidemiology and cost. In M. H. Pope, G. B. J. Andersson, J. W. Frymoyer, & D. B. Chaffin (Eds.), Occupational low back pain: Assessment, treatment, and prevention (pp. 95-113). St. Louis: Mosby.

Bigos, S. J., Battie, M. C., Spengler, D. M., Fisher, L. D., Fordyce, W. E., Hansson, T., Nachemson, A. L., & Zeh, J. (1992). A longitudinal prospective study of industrial back injury reporting. Clinical Orthopaedics, 279, 21-34.

Cady, L. D., Bischoff, D. P., O'Connell, E. R., Thomas, P. C., & Allan, J. H. (1979). Strength and fitness and subsequent back injuries in fire fighters. Journal of Occupational Medicine, 21, 269-272.

Cady, L. D., Thomas, P. C., & Karwasky, R. J. (1985). Program for increasing health and physical fitness of fire fighters. Journal of Occupational Medicine, 27, 110-114.

Chaffin, D. B. (1979). Manual materials handling: The cause of over-exertion injury and illness in industry. Journal of Environmental Pathology and Toxicology, 2, 269-272.

Cohen, A. (1989). Perspectives on self-protective behaviors and work place hazard. In N. E. Weinstein (Ed.), Taking care: Understanding and encouraging self-protective behavior. New York: Cambridge University Press.

Conrad, K. M., Balch, G. I., Reichelt, P. A., Muran, S., & Oh, K. (1994). Musculoskeletal injuries in the fire service. AAOHN Journal, 42(12), 1-10.

Davis, P. O., Dotson, C. O., & Santa Maria, D. L. (1982). Relationship between simulated fire fighting tasks and physical performance measures. Medicine and Science in Sports and Exercise, 14, 65-71.

Department of Health and Human Services. (1986). Proposed national strategy for the prevention of musculoskeletal injuries (DHHS Publication No. 89-129). Washington DC: Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health.

Doolittle, T. L., & Kaiyala, K. (1986). Strength and musculoskeletal injuries of firefighters. Annual Conference of the Human Factors Association of Canada (pp. 49-52). Richmond, British Columbia.

Doolittle, T. L. (1979). Validation of physical requirements for firefighters. (Technical report prepared for the Seattle Fire Department and Office of Management and Budget).

Doolittle, T. L. (1989). Validation of a firefighter physical ability test. (Technical report for the City of Tacoma, WA).

Doormall, M. T. A. J., Drissen, A. P. A., Landeweerd, J. A., & Drost, M. R. (1995). Physical workload of ambulance assistants. Ergonomics, 38, 361-376.

Dotson, C. O., Santa Maria, D. L., Davis, P. O., & Swartz, R. A. (1977). Development of a job-related physical performance examination for fire fighters. College Park: University of Maryland.

Ellam, L. D., Fieldman, G. B., Fordham, M., Goldsmith, R., & Barham, P. (1994). The perception of physical fitness as a guide to its evaluation in firemen. Ergonomics, 37, 943-952.

Gagnon, M., Chehade, A., Kemp, F., Lortie, M. (1987). Lumbo-sacral loads and selected muscle activity while turning patients in bed. Ergonomics, 30, 1013-1032.

Gagnon, M., Sicard, C., & Sirois, J. P. (1986). Evaluation of forces on the lumbo-sacral joint and assessment of work and energy transfers in nursing aides lifting patients. Ergonomics, 29, 407-421.

Hilyer, J. C., Brown, K. C., Sirles, A. T., & Peoples, L. (1990). A flexibility intervention to reduce the incidence and severity of joint injuries among municipal fire fighters. Journal of Occupational Medicine, 32, 631-637.

Hogya, P. T., & Ellis, L. (1990). Evaluation of the injury profile of personnel in a busy urban EMS system. American Journal of Emergency Medicine, 8, 308-311.

International Association of Fire Fighters (1996). 1995 death and injury survey. Washington DC. Author.

Jensen, R. C. (1987). Disabling back injuries among nursing personnel: Research needs and justification. Research in Nursing and Health, 10, 29-38.

Karter, M. J., & LeBlanc, P. R. (1996). U.S. fire fighter injuries in 1995. NFPA Journal, 90(6), 56-67.

Lavender, S. A., Conrad, K. C., Reichelt, P. R., Meyer, F. T., & Johnson, P. W. Biomechanical analyses of frequently performed strenuous work tasks encountered by firefighter/paramedics. Manuscript submitted for publication.

LeCuyer, J. (1994). Where tools and people meet. Fire Chief, 34-41.

Lemon, P. W., & Hermiston, R. T. (1977). The human energy cost of fire fighting. Journal of Occupational Medicine, 19, 558-562.

Marras, W. S., & Kim, J. Y. (1993). Anthropometry in industrial populations. Ergonomics, 36, 371-378.

Marras, W. S., Lavender, S. A., Leurgans, S. E., Rajulu, S. L., Allread, W. G., Fathallah, F. A., & Ferguson, S. A. (1993). The role of dynamic three-dimensional trunk motion in occupationally-related low back disorders: The effects of workplace factors, trunk position, and trunk motion characteristics on risk of injury. Spine, 5, 617-628.

Matticks, C. A., Westwater, J. J., Himel, H. N., Morgan, R. F., & Edlich, R. F. (1992). Health risks to fire fighters. Journal of Burn Care Rehabilitation, 13, 223-235.

Praemer, M. A., Furner, S., & Rice, D. P. (1992). Musculoskeletal conditions in the United States. Park Ridge, IL: American Academy of Orthopaedic Surgeons.

Reichelt, P. A., & Conrad, K. M. (1995). Musculoskeletal injury: Ergonomics and physical fitness. In R. Duffy, J. Melius, & P. Orris (Vol. Eds.), Occupational medicine: State of the art reviews: Vol. 10(3). Firefighters. Philadelphia, PA: Hanley Belfus.

Romet, T. T., & Frim, J. (1987). Physiological responses to fire fighting activities. European Journal of Applied Physiology, 56, 633-638.

Stilwell, J. A., & Stilwell, P. J. (1984). Sickness absence in an ambulance service. Journal of the Society for Occupational Medicine, 34, 96-99.

Sullivan, C., & Yuen, J. (1986). Predictors of work-related back injuries among fire fighters. Proceedings of the Fifth International Symposium on Epidemiology in Occupational Health (p. 165).

Tsuang, Y. H., Schipplein, O. D., Trafimow, J. H., & Andersson, G. B. J. (1992). Influence of body segment dynamics on loads at the lumbar spine during lifting. Ergonomics, 35, 437-444.

Webb Associates (1978). Anthropometric source book: Volume II. National Aeronautics and Space Administration.

Table 1

SUMMARY OF SIGNIFICANT FINDINGS AND USEFULNESS OF FINDINGS BY SPECIFIC AIM

Aim #1: Identify Frequently Performed, Physically Strenuous EMS Tasks

Significant Findings:

- Interviewees nominated the 11 most frequently performed and strenuous EMS tasks.
- A survey (N = 374) confirmed that the 11 EMS tasks identified during interviews were the most strenuous and frequently-performed ones in the 14 participating fire departments.
- The 11 EMS tasks were ranked on a composite score derived from survey ratings of frequency and strenuousness.

Usefulness of Findings:

- The interview findings provided the content for the reliable and valid survey questionnaire developed in this study. The questionnaire can be used for ergonomic investigations in other fire service populations.
- The survey results guided the selection of tasks for the simulation phase of the study.
- The survey results provide statistical validation of the list of fire service EMS tasks most in need of ergonomic improvement.

Aim #2: Conduct Ergonomic Task Analysis

Significant Findings:

- The task simulations produced reliable and valid ergonomic data about EMS work.
- Work postures for frequently-performed, strenuous EMS tasks were recorded and quantified.
- Forces applied by FF/Ps as they performed the strenuous EMS tasks were calculated.
- Strength limitations and spine compression forces for each EMS task were calculated using the University of Michigan Three-Dimensional Static Strength Prediction Model.
- The relative risks for low back disorder (LBD) associated with each EMS task were calculated using the Trunk Motion Logistic Regression Model developed at Ohio State University.

Usefulness of Findings:

- The simulation methodology developed here will allow further investigation of EMS tasks that cannot be observed during real operations because of practical, legal, and ethical constraints.

- The following three categories of findings indicate the risk of three different categories of injuries associated with each EMS task component. This information can be used to generate cost/benefit analyses for proposed work method or equipment redesign interventions targeted at each task component. The cost/benefit analyses can then be used to determine the relative priority of different ergonomic interventions.

  - The LBD risk analysis identified the EMS task components that contribute the most to the development of cumulative trauma back injuries.

  - The strength limitation calculations indicated the EMS task components during which musculoskeletal overexertion injuries are most likely to occur.

  - The spine compression calculations indicated the EMS task components during which disc-related back injuries are most likely to occur.

- Task analyses provide a basis for task-specific training and physical-conditioning programs.

Aim #3: Hypothesize Methods to Reduce Musculoskeletal Stress in Riskiest EMS Tasks.

Significant Findings:

Based on the ergonomic task analyses, the following equipment modifications (and related work method changes) are hypothesized to be feasible ways of reducing the risk of musculoskeletal injuries during frequently-performed, strenuous EMS tasks:

- A waist-supported, hands-free system for backboard transport.

- An articulated backboard with a locking mechanism.

- An adjustable length backboard with a locking mechanism.

- A low friction bed-to-stretcher interface.

- A tri-wheel stairchair.

Usefulness of Findings:

- The hypothesized modifications provide specific targets for future research efforts.

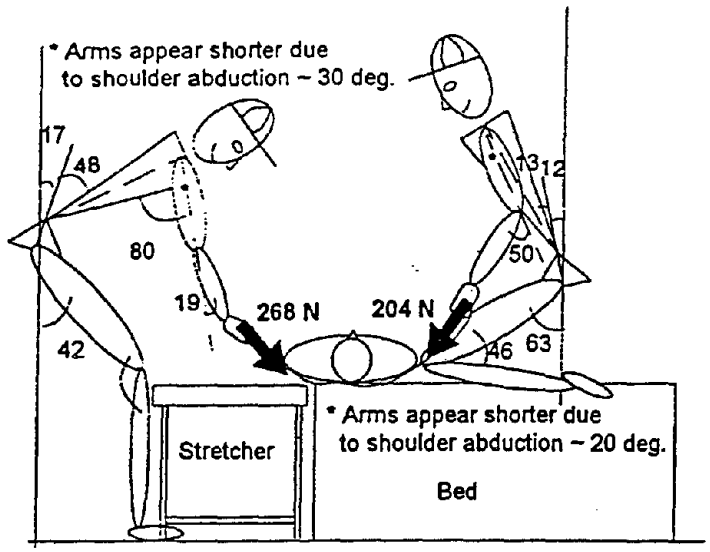
- The hypothesized EMS equipment and work-method modifications would be relatively simple ones to build and test.

Table 2.

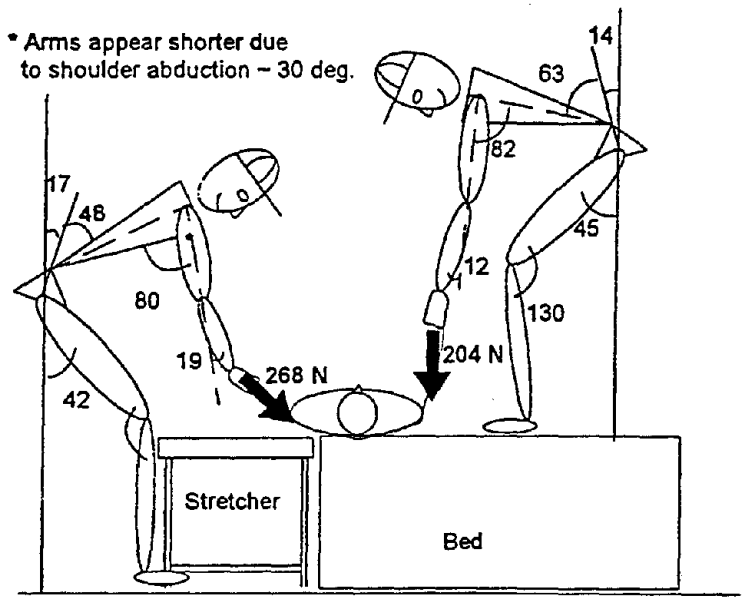
Task components performed during transport tasks involving stairs

Transport Task	Initial Lift	Initiate Stair Descent	Mid-Stair Carry	Around The Landing
Stairchair		X	X	X
Backboard	X	X	X	X
Stretcher		X	X	
Slat-Stretcher	X	X	X	X

Note. (All tasks, excepting the slat-stretcher transport, were selected on the basis of both interview and survey data.)

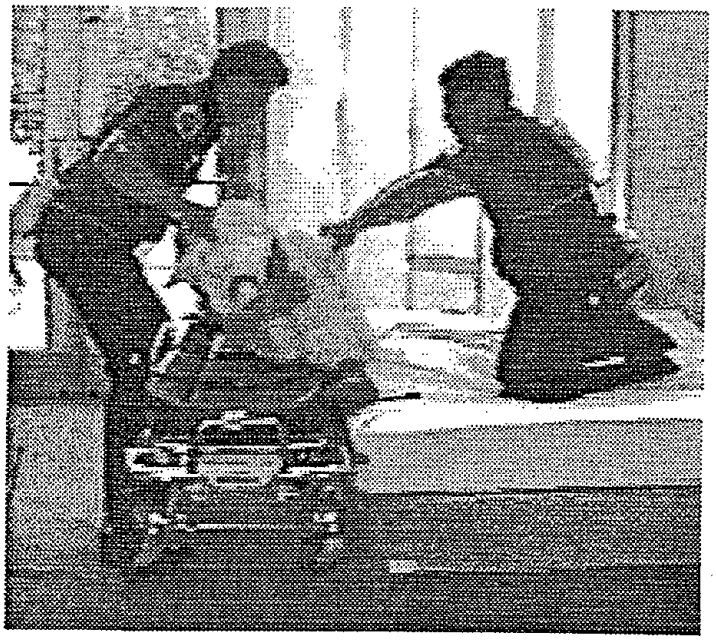


(a)



(b)

Figures 1(a) & 1(b). The Bed-to-Stretcher-Transfer Task. Figure 1(a) shows the kneeling method. Figure 1(b) shows the standing method.



(a)

(b)

Figure 2(a) & 2(b). The Bed-to-Stretcher-Transfer Task. Figure 2(a) shows the kneeling method. Figure 2(b) shows the standing method. The video images show differences between the kneeling and standing postures as the firefighter/paramedic on the bed completes the last strenuous component of the task.

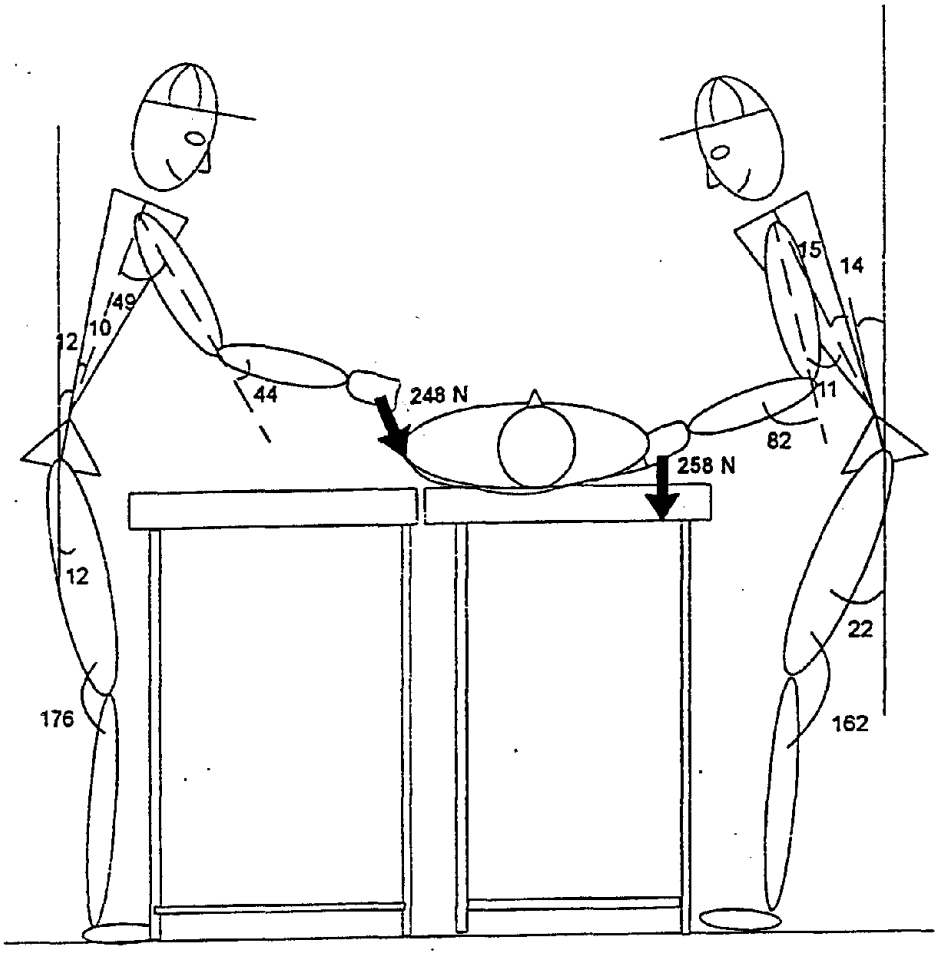
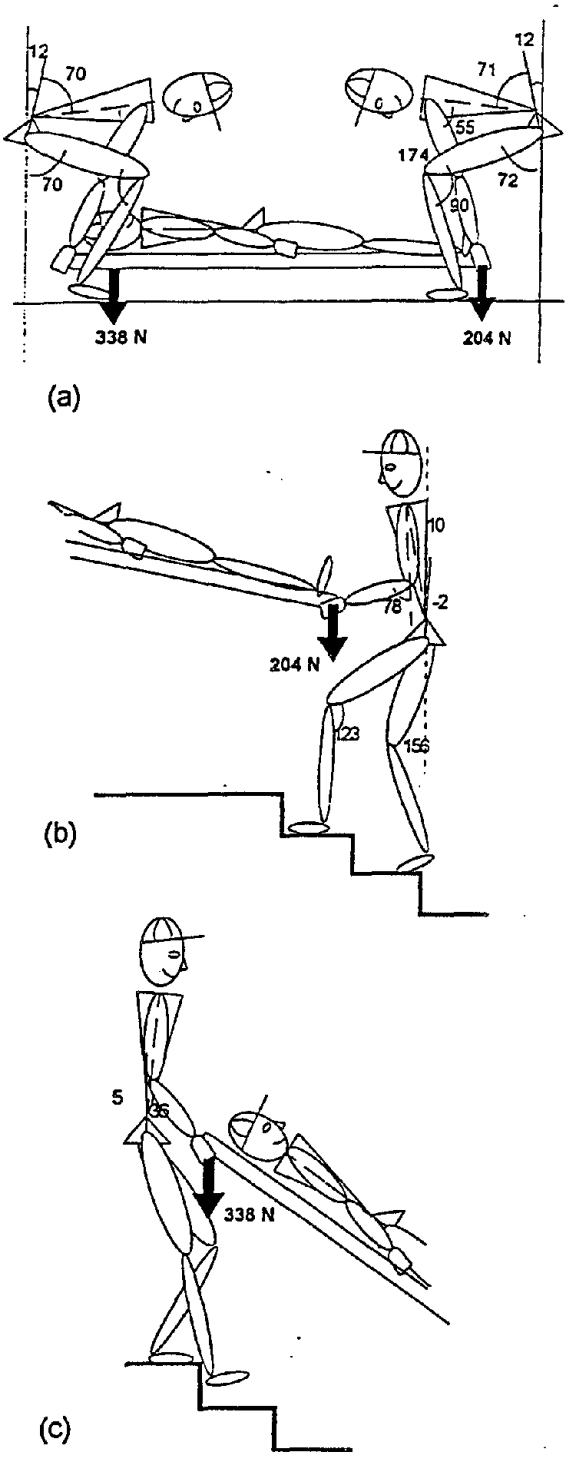
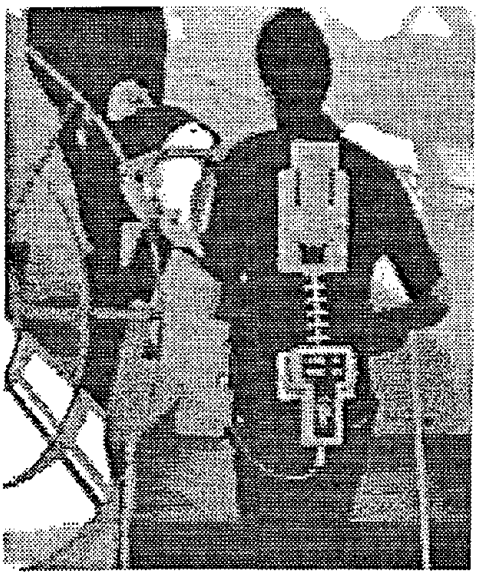


Figure 3. The Stretcher-to-Gurney-Transfer Task. The firefighter/paramedic (FF/P) on the left in this figure both lifts and pulls the victim. The FF/P on the right assists by lifting the victim.

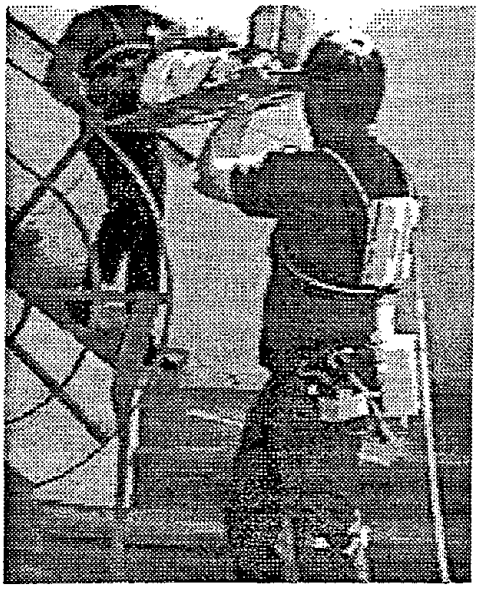


Figures 4(a), (b), & (c). The Transport-Down-Stairs-with-Backboard Task. Figure 4(a) shows the first component of the task ("initial lift"). Figure 4(b) shows the second component ("initiate stair descent"). The firefighter/paramedic (FF/P) shown in Figure 4(b) is the "leader" in the task. The leader descends first and makes the descent walking backward. Figure 4(c) shows the third component ("mid-stair carry"). The FF/P shown in Figure 4(c) is the "follower" in this task. The follower makes the descent walking forward.

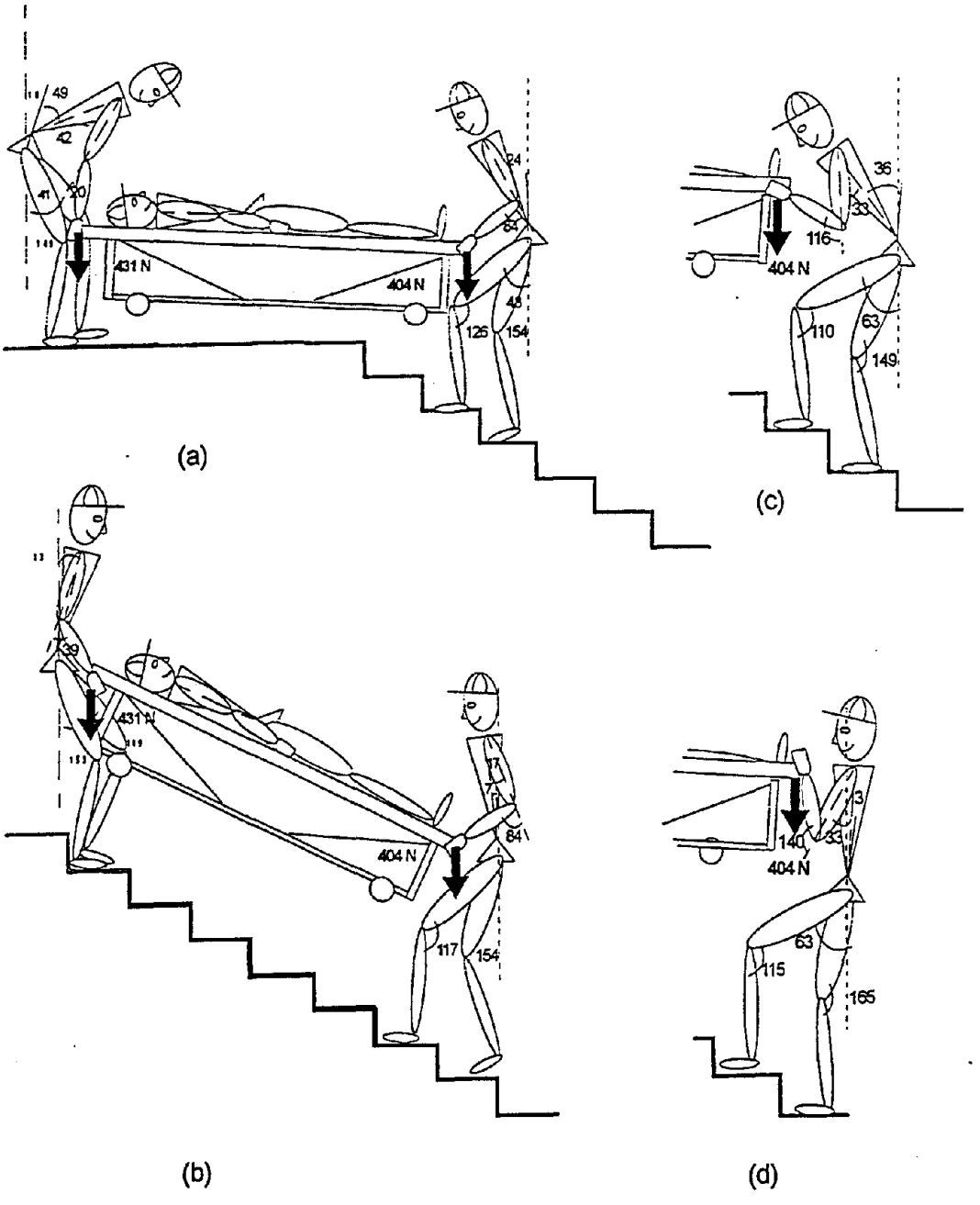
(a)



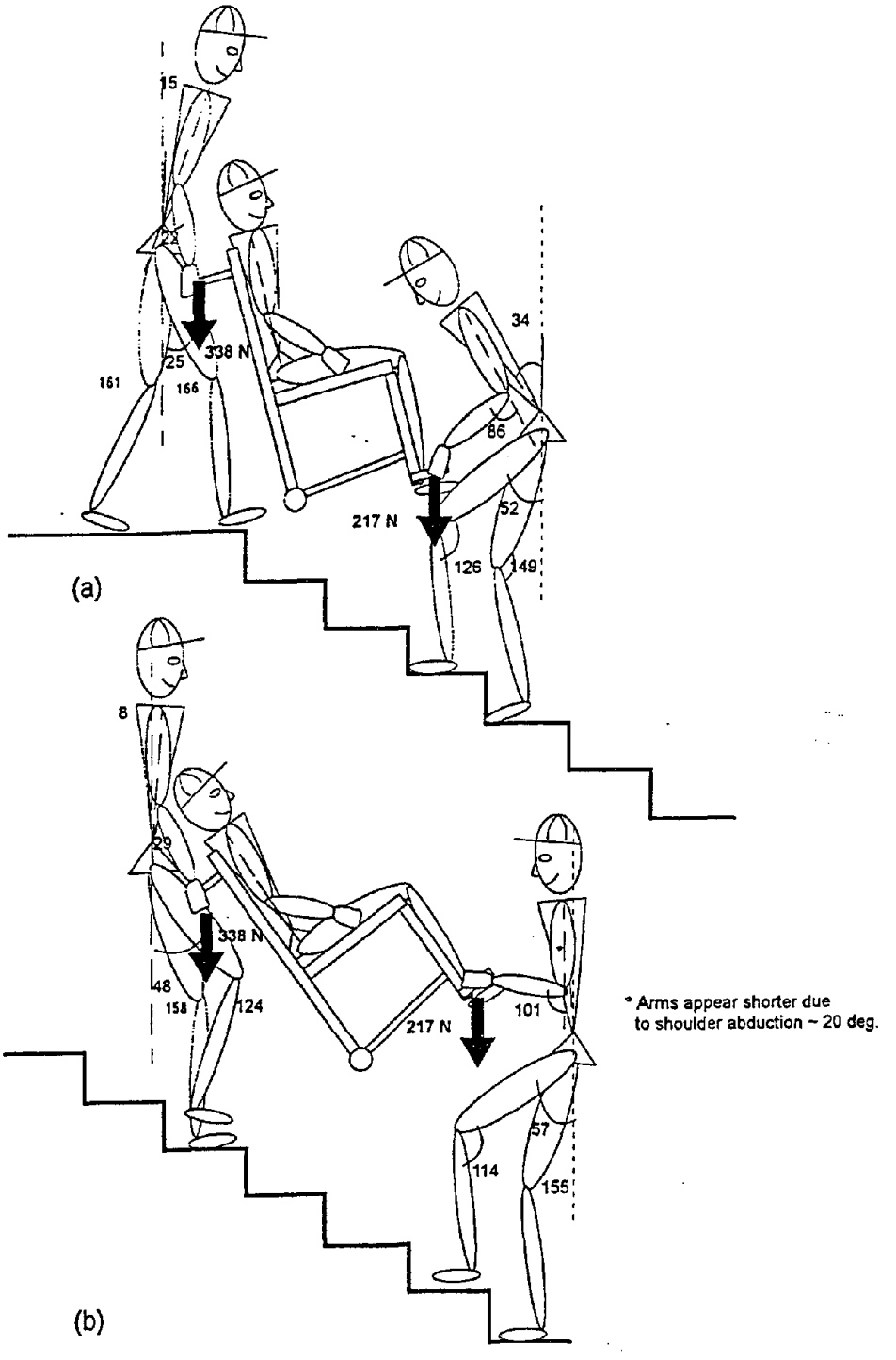
(b)



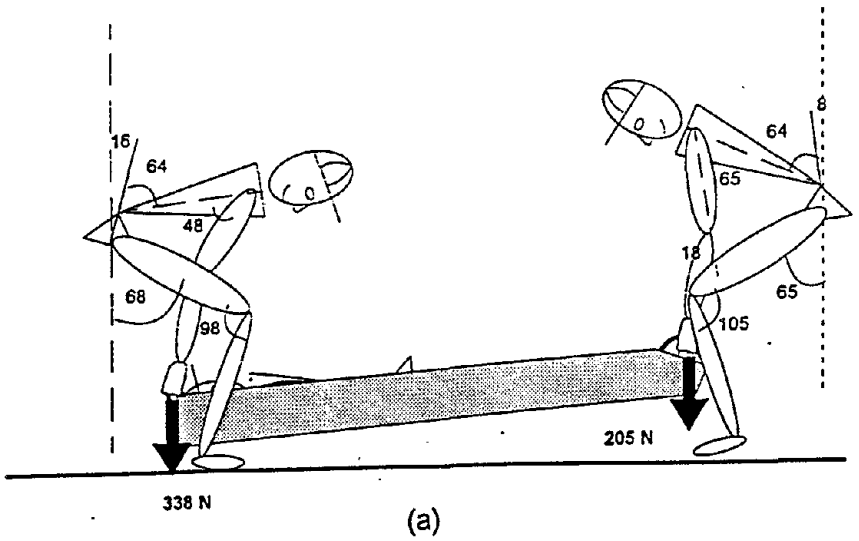
Figures 5(a) & (b). The Transport-Down-Stairs-with-Backboard Task. Shown are two different postures the firefighter/paramedic (FF/P) in the "leader" role may take as he negotiates the fourth component of the task ("around-the-landing"). (The leader is the FF/P on the right in both figures.) In Figure 5(a) the leader has his arms in the lowered position. In Figure 5(b) the leader is performing the same task component with his arms raised. Figure 5(a) shows the Lumbar Motion Monitor strapped to the leader's back. The cable to the radio transmitter can be seen emerging from the bottom of the unit. Figure 5(b) shows the radio transmitter hanging from a harness over the leader's left hip.



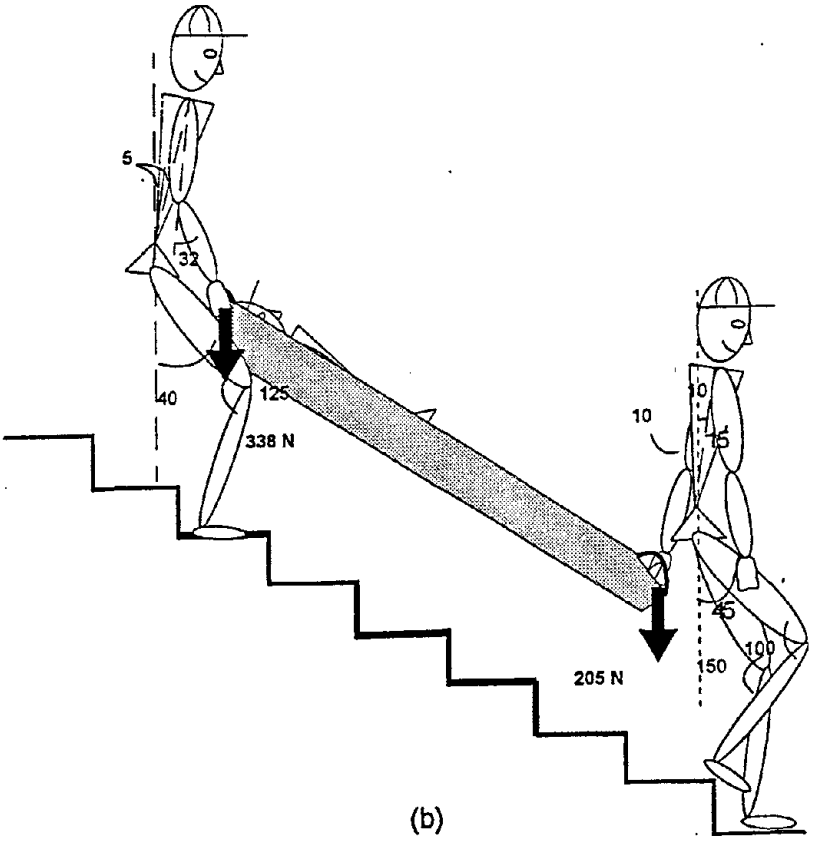
Figures 6(a), (b), (c), & (d). The Transport-Down-Stairs-with-Stretcher Task. Figure 6(a) shows the first component of the task ("initiate stair descent"). Figure 6(b) shows the second component ("mid-stair carry"). The lower firefighter/paramedic is the "leader" in the task. Figure 6(b) shows the leader carrying the stretcher at waist height, with the elbows extended. Figure 6(c) shows the leader shifting postures, to one in which the elbows are flexed and the stretcher is held at chin height, as shown in Figure 6(d).



Figures 7(a) & (b). The Transport-Down-Stairs-with-Stairchair Task. Figure 7(a) shows the first component of the task ("initiate stair descent"). Figure 7(b) shows the second component ("mid-stair carry"). Both firefighter/paramedics (FF/Ps) are shown using the handles built into the stairchair. The lower FF/P is the "leader" in the task. The upper FF/P is the "follower" in the task.



(a)



(b)

Figures 8(a) & (b). The Transport-Down-Stairs-with-Slat-Stretcher Task. Figure 8(a) shows the first component of the task ("initial lift"). Figure 8(b) shows the third component ("mid-stair carry"). The lower firefighter/paramedic (FF/P) is the "leader" in the task. The upper FF/P is the "follower" in the task. Figure 8(b) also shows the leader grasping the slat-stretcher with only his left hand during the "mid-stair carry." The right hand remains free. It can be used to grab hold of a railing or brace against a wall, if necessary.

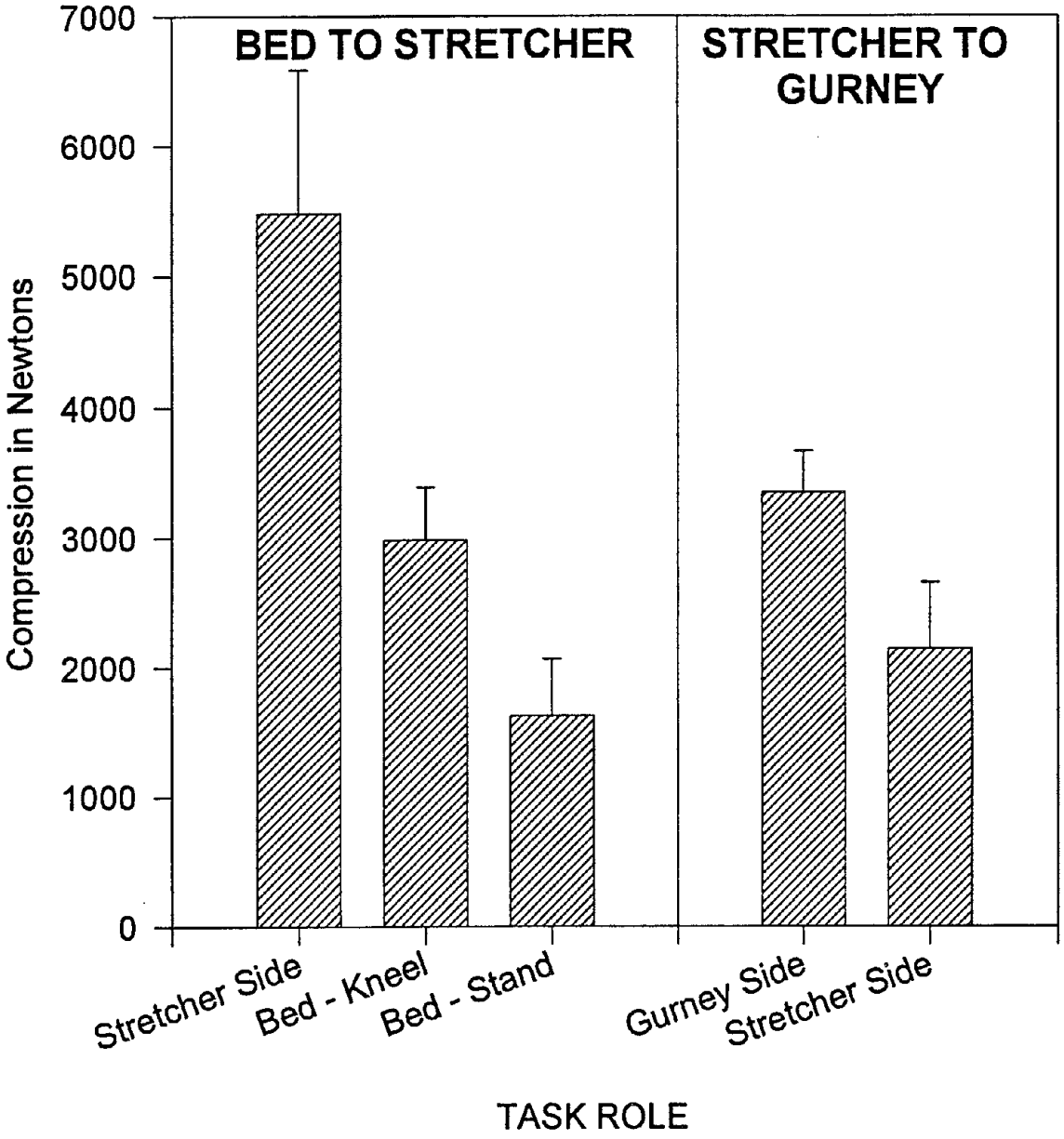


Figure 9. The mean compression values for the bed-to-stretcher and the stretcher-to-gurney tasks as a funciton of the role and method variations.

Figure 10. The probability that performing a specific role in a specific task component by a particular method is representative of a cluster of task performance elements associated with a high historical incidence of low back disorders. Each row of the table represents a different cluster of task performance elements. The different clusters are ranked from high to low in terms of probability values. The probability values are from the Logistic Regression Model.

TASK		COMPONENT		ROLE	METHOD	PROBABILITY
Stretcher	Transport	Initiate	Stairs	Leader	Raised	98.3
Stretcher	Transport	Initiate	Stairs	Leader	Normal	96.6
Bed-to-Stretcher	Transfer	Stretcher-Side		Pull	normal	96.2
Slat-Stretcher	Transport	Initial	Lift	Follower	normal	95.4
Backboard	Transport	Initial	Lift	Follower	normal	91.4
Bed-to-Stretcher	Transfer	Bed-Side		Push	normal	88.9
Stretcher	Transport	Initiate	Stairs	Follower	normal	85.1
Stretcher	Transport	On	Stairs	Leader	Normal	83.8
Stretcher	Transport	On	Stairs	Leader	Raised	82.1
Stretcher-To-Gurney	Transfer	Stretcher-Side		Push	normal	78.2
Backboard	Transport	Initial	Lift	Leader	normal	75.1
Stretcher-To-Gurney	Transfer	Gurney-Side		Pull	normal	73.4
Slat-Stretcher	Transport	Negotiate	Landing	Follower	normal	73.1
Slat-Stretcher	Transport	Initial	Lift	Leader	normal	70.5
Slat-Stretcher	Transport	On	Stairs	Follower	normal	66.0
Slat-Stretcher	Transport	Initiate	Stairs	Follower	normal	61.4
Stairchair	Transport	Initiate	Stairs	Leader	normal	56.9
Backboard	Transport	Negotiate	Landing	Leader	Raised	56.1
Stairchair	Transport	On	Stairs	Leader	normal	48.0
Backboard	Transport	On	Stairs	Leader	normal	39.5
Backboard	Transport	Initiate	Stairs	Leader	normal	39.2
Stairchair	Transport	Negotiate	Landing	Leader	normal	37.9
Backboard	Transport	Negotiate	Landing	Follower	normal	37.2
Backboard	Transport	On	Stairs	Follower	normal	35.7
Stairchair	Transport	Initiate	Stairs	Follower	normal	32.2
Stairchair	Transport	On	Stairs	Follower	normal	31.9
Stretcher	Transport	On	Stairs	Follower	normal	31.8
Backboard	Transport	Negotiate	Landing	Leader	Normal	29.3
Slat-Stretcher	Transport	On	Stairs	Leader	One-hand	27.7
Slat-Stretcher	Transport	Negotiate	Landing	Leader	One-hand	27.5
Stairchair	Transport	Negotiate	Landing	Follower	normal	27.3
Slat-Stretcher	Transport	Initiate	Stairs	Leader	One-hand	25.2
Slat-Stretcher	Transport	Initiate	Stairs	Leader	Two-hand	24.0
Slat-Stretcher	Transport	On	Stairs	Leader	Two-hand	18.7
Backboard	Transport	Initiate	Stairs	Follower	normal	16.8
Slat-Stretcher	Transport	Negotiate	Landing	Leader	Two-hand	13.2

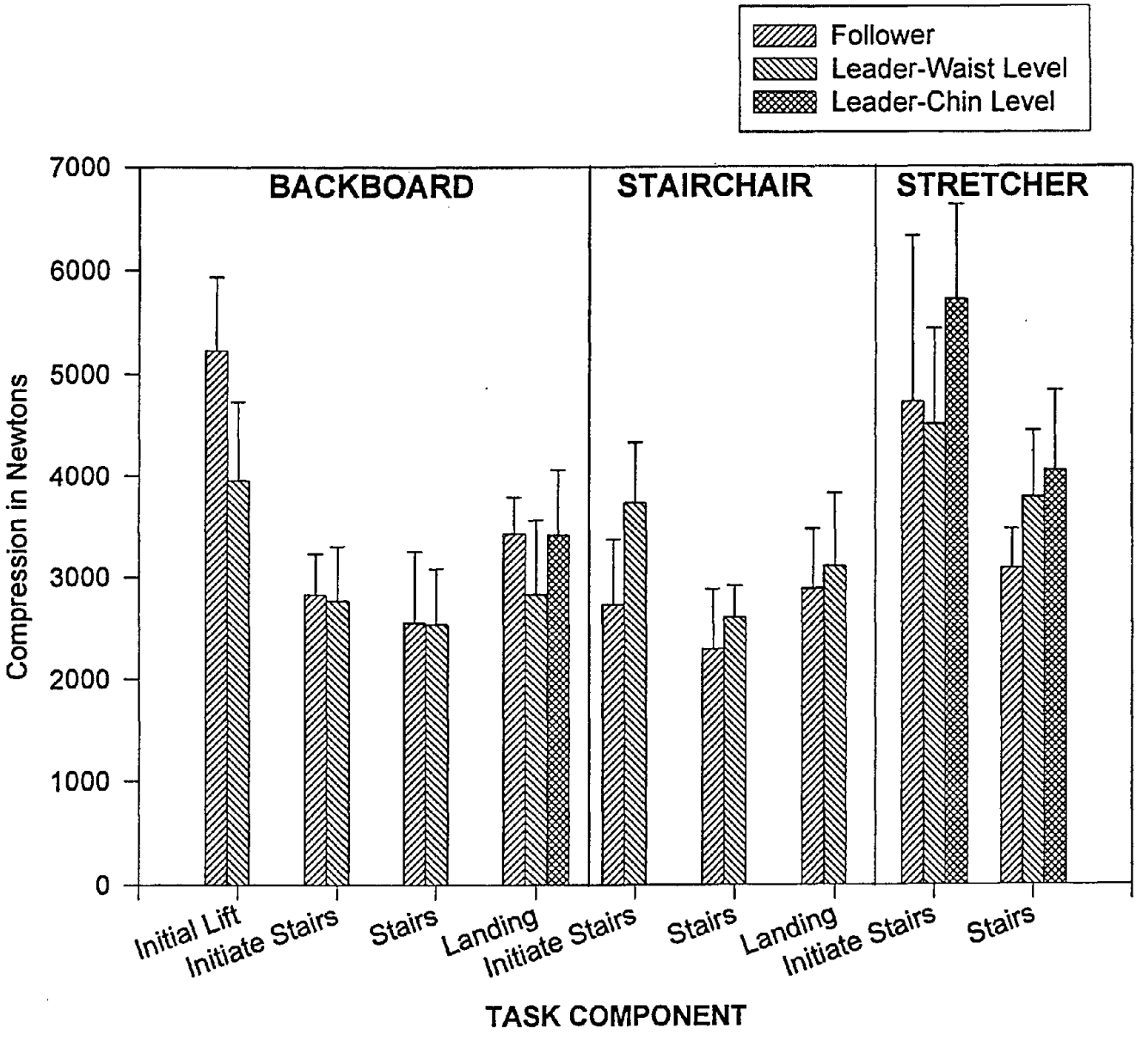


Figure 11. The mean compression values (Newtons) for the backboard, stairchair, and stretcher trasport tasks as a function of task component, role, and method variation.

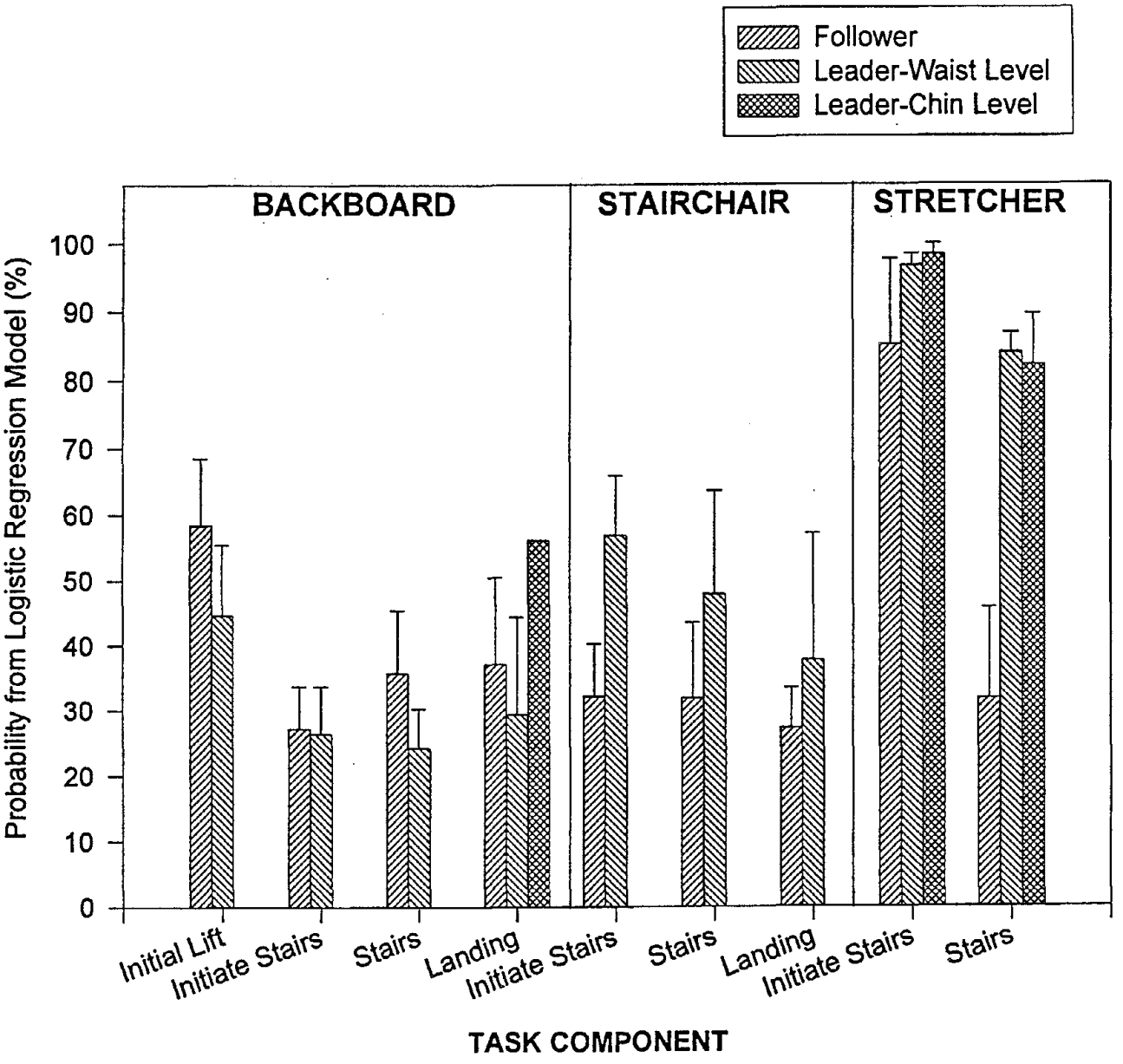


Figure 12. The mean probability values from the logistic regression model indicating the likelihood that the model tasks are representative of tasks with a high historical incidence rate of low back disorders.

PLANNED PUBLICATIONS

Conrad, K. M., Lavender, S. A., Reichelt, P. A., Meyer, F. T., Marks, B. Firefighters simulating frequently performed strenuous EMS tasks: Overview of methods and results.

Lavender, S. A., Conrad, K. M., Reichelt, P. A., Meyer, F. T., & Johnson, P. W. Postural analyses of firefighters simulating frequently performed strenuous EMS tasks.

Lavender, S. A., Conrad, K. M., Reichelt, P. A., Meyer, F. T., & Johnson, P. W. Biomechanical analyses of firefighters simulating frequently performed strenuous EMS tasks.

UIC The University of Illinois at Chicago

Principal Investigator: Conrad, Karen M. NIOSH 5 RO3 OH03123-02

APPENDIX A -- "Fire Service Survey" Booklet

FIRE SERVICE SURVEY

SEPTEMBER 1995

Conducted by:
The Survey Research Laboratory
University of Illinois at Chicago

Principal Investigator:
Karen Conrad, Director
University of Illinois at Chicago
Fire Service Project

FIRE SERVICE SURVEY

SEPTEMBER 1995

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INSTRUCTIONS

The purpose of this survey is to learn which frequently performed EMS tasks are the most strenuous for the widest range of firefighters. This survey describes common EMS tasks. Descriptions for the tasks are based on interviews with MABAS III fire service personnel. We understand that each EMS run presents different working conditions, and that different personnel will tackle a specific task differently. However, please use your experience to estimate how frequently you perform the task as described and how strenuous the task would be as described.

Most of the tasks are described as being performed by two workers, Worker 1 and Worker 2. The job performed by Worker 1 is labeled Job 1; the job performed by Worker 2 is labeled Job 2. If a task is described as being performed by only two workers, rate the strenuousness of the work as it would be if performed by only two workers, even if your work group usually performs the task with more than two workers. Also, rate how frequently you perform the task with only two workers. In each case, assume that the patient is an average-sized adult male. Make these ratings based on your own personal experience. It is expected that different people will rate tasks somewhat differently.

Do not write your name on this survey form. It has been given an identifying number that will tell us who returned it. However, we do not want your name associated with this survey information once the questionnaire has been checked in.

When you have finished filling out the questionnaire, seal it in the enclosed envelope and mail it to the Survey Research Laboratory.

If you have any questions about the study or how to complete the survey, call Karen Conrad, Director of the UIC Fire Service Project, at (312) 996-7974 or Lynn Hamilton, Project Coordinator at the Survey Research Laboratory, (312) 996-5560. Voicemail is attached, so you can call at any time.

Thanks for your cooperation. Working together we can reduce musculoskeletal injury in the fire service.

INTRODUCTION TO THE EMS TASK SURVEY

EXAMPLE QUESTION:
Here is how the survey works: First, read the description of the task. Next, recall how often you do the jobs involved and how strenuous they are for you, **ON AVERAGE.** Finally, answer the four questions regarding each task. Below is an example for Job 1.

Sample Task
Two workers lift a patient on a backboard from the floor (ground) to the height of a stretcher that has its undercarriage fully extended. There are two jobs in this task.

JOB 1. Worker 1 squats at the head of the backboard, grasps it, and then straightens up, lifting the head of the backboard.

JOB 2. Worker 2 squats at the foot of the backboard, grasps it, and then straightens up, lifting the foot of the backboard.

Example A. Out of every 10 emergency calls, on approximately how many calls do you perform **JOB 1**?

Less than 1 call in every 10 ..... (1)

1-2 calls out of every 10 2

3-4 calls out of every 10 3

5-6 calls out of every 10 4

7-8 calls out of every 10 5

9-10 calls out of every 10 6

For example A, the firefighter has circled response 1 because he/she squats at the head of the backboard and lifts less than 1 time in every 10 calls, on average.

Example B. How physically strenuous is **JOB 1** for you?

Not strenuous 1

Somewhat strenuous 2

Strenuous ..... (3)

Very strenuous 4

For example B, the firefighter has circled response 3 because he/she feels that lifting an average-sized male patient up in this manner is strenuous. The firefighter would continue with the survey by answering the same questions imagining he/she was doing Job 2.

IMAGINE YOURSELF IN THE FOLLOWING SITUATIONS AND ANSWER THE QUESTIONS BELOW ACCORDINGLY. PLEASE KEEP IN MIND THAT ALL SITUATIONS ASSUME THAT THE PATIENT IS AN AVERAGE-SIZED MALE.

CIRCLE ONLY ONE RESPONSE FOR EACH QUESTION.

Task 1: **Two workers** remove a patient from an auto on a **backboard**.

There has been an auto accident. The auto has not been severely compressed and the door opening has not been severely altered. The driver or a passenger must be transferred from a sitting position in the front seat to a prone position on a backboard that rests on the seat. There are two separate jobs in this task.

JOB 1. Worker 1 is at the foot of the backboard and closest to the patient. Worker 1 turns the patient, lowers the patient to the backboard, and then pulls the patient onto the backboard. Worker 1 then lifts the foot of the backboard off the seat and out of the auto.

JOB 2. Worker 2 is at the head of the backboard and furthest from the patient. Worker 2 supports and steadies the backboard while the patient is being lowered onto the backboard. Then Worker 2 lifts and carries the head of the backboard as the patient is moved out of and away from the auto.

1. Out of every 10 emergency calls, on approximately how many calls do you perform **JOB 1**?

Less than 1 call in every 10 1

1-2 calls out of every 10 2

3-4 calls out of every 10 3

5-6 calls out of every 10 4

7-8 calls out of every 10 5

9-10 calls out of every 10 6

2. How physically strenuous is **JOB 1** for you?

Not strenuous 1

Somewhat strenuous 2

Strenuous 3

Very strenuous 4

3. Out of every 10 emergency calls, on approximately how many calls do you perform **JOB 2**?

Less than 1 call in every 10 1

1-2 calls out of every 10 2

3-4 calls out of every 10 3

5-6 calls out of every 10 4

7-8 calls out of every 10 5

9-10 calls out of every 10 6

4. How physically strenuous is **JOB 2** for you?

Not strenuous 1

Somewhat strenuous 2

Strenuous 3

Very strenuous 4

Task 2: **Two workers** lift a patient from the floor for transfer to a bed or stretcher.

The patient is sitting or lying on the floor (ground). There is enough room for one worker to lift the patient at the torso and the other to lift the patient at the legs (a backboard is not required). The workers lift the patient high enough so that they can walk while carrying him. There are two separate jobs in this task.

JOB 1. Worker 1 lifts the patient at the torso, lifting from a position behind the patient.

JOB 2. Worker 2 lifts the patient at the legs, lifting from a position facing the patient.

5. Out of every 10 emergency calls, on approximately how many calls do you perform **JOB 1**?

Less than 1 call in every 10 1

1-2 calls out of every 10 2

3-4 calls out of every 10 3

5-6 calls out of every 10 4

7-8 calls out of every 10 5

9-10 calls out of every 10 6

6. How physically strenuous is **JOB 1** for you?

Not strenuous 1

Somewhat strenuous 2

Strenuous 3

Very strenuous 4

7. Out of every 10 emergency calls, on approximately how many calls do you perform **JOB 2**?

Less than 1 call in every 10 1

1-2 calls out of every 10 2

3-4 calls out of every 10 3

5-6 calls out of every 10 4

7-8 calls out of every 10 5

9-10 calls out of every 10 6

8. How physically strenuous is **JOB 2** for you?

Not strenuous 1

Somewhat strenuous 2

Strenuous 3

Very strenuous 4

Task 3: **Two workers** transfer a patient from a bed to a stretcher using **sheets**.

The patient is lying in bed at home. The stretcher is placed alongside the bed. The physical layout of people and objects require that Worker 1 kneel on the bed at the side of the patient. Worker 2 stands at the side of the stretcher. Each grasps the sheet under the patient with two hands and lifts and shifts the patient from the bed to the stretcher. (The patient is not on a backboard.) There are two separate jobs in this task.

JOB 1. Worker 1, kneeling on the bed, lifts the patient toward and onto the stretcher. The complete shift to the stretcher may take place in several separate lifts and shifts, during which Worker 1 moves forward on the bed on knees toward the stretcher.

JOB 2. Worker 2, standing beside the stretcher, leans across the stretcher and pulls the patient toward and onto the stretcher.

9. Out of every 10 emergency calls, on approximately how many calls do you perform **JOB 1**?

Less than 1 call in every 10 1

1-2 calls out of every 10 2

3-4 calls out of every 10 3

5-6 calls out of every 10 4

7-8 calls out of every 10 5

9-10 calls out of every 10 6

10. How physically strenuous is **JOB 1** for you?

Not strenuous 1

Somewhat strenuous 2

Strenuous 3

Very strenuous 4

11. Out of every 10 emergency calls, on approximately how many calls do you perform **JOB 2**?

Less than 1 call in every 10 1

1-2 calls out of every 10 2

3-4 calls out of every 10 3

5-6 calls out of every 10 4

7-8 calls out of every 10 5

9-10 calls out of every 10 6

12. How physically strenuous is **JOB 2** for you?

Not strenuous 1

Somewhat strenuous 2

Strenuous 3

Very strenuous 4

Task 4: **Two workers** move a patient from a bed on a **backboard**.

This task begins when a patient has been placed on a backboard but the backboard with the patient on it is still lying on the bed. The task consists of lifting the backboard loaded with the patient off the bed for transfer to a stretcher. There are two separate jobs in this task.

JOB 1. Worker 1 is standing at the side of the bed near its head. (The physical layout prevents Worker 1 from standing at the head of the bed.) Worker 1 twists and leans in over the bed, grips the head of the backboard, and twists away from the bed, bringing the head of the backboard up and away from the bed.

JOB 2. Worker 2 is standing at the foot of the bed in line with the backboard. Worker 2 leans forward, grips the foot of the backboard, lifts it up off the bed, and steps sideways to bring the backboard away from the bed.

13. Out of every 10 emergency calls, on approximately how many calls do you perform **JOB 1**?

Less than 1 call in every 10 1

1-2 calls out of every 10 2

3-4 calls out of every 10 3

5-6 calls out of every 10 4

7-8 calls out of every 10 5

9-10 calls out of every 10 6

14. How physically strenuous is **JOB 1** for you?

Not strenuous 1

Somewhat strenuous 2

Strenuous 3

Very strenuous 4

15. Out of every 10 emergency calls, on approximately how many calls do you perform **JOB 2**?

Less than 1 call in every 10 1

1-2 calls out of every 10 2

3-4 calls out of every 10 3

5-6 calls out of every 10 4

7-8 calls out of every 10 5

9-10 calls out of every 10 6

16. How physically strenuous is **JOB 2** for you?

Not strenuous 1

Somewhat strenuous 2

Strenuous 3

Very strenuous 4

Task 5: **Two workers** secure a patient in a confined space to a **backboard**.

The patient has fallen off a toilet in a small bathroom. The patient is lying between the toilet and the wall. A backboard must be wedged in next to the patient and the patient must be secured to the backboard. There are two jobs in this task.

JOB 1. Worker 1 shifts the torso of the patient onto the backboard and secures the upper half of the patient to the backboard.

JOB 2. Worker 2 shifts the legs of the patient onto the backboard and secures the lower half of the patient to the backboard.

17. Out of every 10 emergency calls, on approximately how many calls do you perform **JOB 1**?

Less than 1 call in every 10 1

1-2 calls out of every 10 2

3-4 calls out of every 10 3

5-6 calls out of every 10 4

7-8 calls out of every 10 5

9-10 calls out of every 10 6

18. How physically strenuous is **JOB 1** for you?

Not strenuous 1

Somewhat strenuous 2

Strenuous 3

Very strenuous 4

19. Out of every 10 emergency calls, on approximately how many calls do you perform **JOB 2**?

Less than 1 call in every 10 1

1-2 calls out of every 10 2

3-4 calls out of every 10 3

5-6 calls out of every 10 4

7-8 calls out of every 10 5

9-10 calls out of every 10 6

20. How physically strenuous is **JOB 2** for you?

Not strenuous 1

Somewhat strenuous 2

Strenuous 3

Very strenuous 4

TASKS 6 THROUGH 11 INVOLVE MOVING A PATIENT DOWNSTAIRS USING VARIOUS KINDS OF EQUIPMENT AND DIFFERENT NUMBERS OF WORKERS. WE MAKE A DISTINCTION BETWEEN TWO KINDS OF PHYSICAL ACTIVITY. THE FIRST IS CARRYING THE PATIENT DOWN THE SECTION OF STAIRWAY THAT IS A STRAIGHT LINE OF STEPS. THE SECOND IS MANEUVERING THE PATIENT AROUND A TIGHT CURVE IN THE STAIRWAY TO ACCOMPLISH A 180-DEGREE CHANGE IN DIRECTION. (A LANDING IS USUALLY INVOLVED IN THE SECOND ACTIVITY.)

Task 6: **Two workers** carry a patient on a **backboard** down a straight line of steps.

This task is part of carrying a patient downstairs on a backboard. The construction of the stairway permits use of a backboard, but the weight of the patient and backboard is being carried by only two workers. In this task, the workers are moving down the section of stairway that is a straight line of steps. There are two separate jobs in this task.

JOB 1. Worker 1 is in the higher position on the stairs, going forward down the steps.

JOB 2. Worker 2 is in the lower position on the stairs, going backward down the steps.

21. Out of every 10 emergency calls, on approximately how many calls do you perform **JOB 1**?

Less than 1 call in every 10 1

1-2 calls out of every 10 2

3-4 calls out of every 10 3

5-6 calls out of every 10 4

7-8 calls out of every 10 5

9-10 calls out of every 10 6

22. How physically strenuous is **JOB 1** for you?

Not strenuous 1

Somewhat strenuous 2

Strenuous 3

Very strenuous 4

23. Out of every 10 emergency calls, on approximately how many calls do you perform **JOB 2**?

Less than 1 call in every 10 1

1-2 calls out of every 10 2

3-4 calls out of every 10 3

5-6 calls out of every 10 4

7-8 calls out of every 10 5

9-10 calls out of every 10 6

24. How physically strenuous is **JOB 2** for you?

Not strenuous 1

Somewhat strenuous 2

Strenuous 3

Very strenuous 4

Task 7: **Two workers** carry a patient on a **backboard** around a curve in the stairway.

This task is part of carrying a patient downstairs on a backboard. The construction of the stairway permits use of a backboard, but the weight of the patient and backboard is being carried by only two workers. In this task, the backboard holding the patient is being maneuvered around a curve or change of direction in the stairway. The space available to maneuver is cramped. There are two separate jobs in this task.

JOB 1. Worker 1 is handling the head of the backboard (upper end).

JOB 2. Worker 2 is handling the foot of the backboard (lower end).

25. Out of every 10 emergency calls, on approximately how many calls do you perform **JOB 1**?

Less than 1 call in every 10 1

1-2 calls out of every 10 2

3-4 calls out of every 10 3

5-6 calls out of every 10 4

7-8 calls out of every 10 5

9-10 calls out of every 10 6

26. How physically strenuous is **JOB 1** for you?

Not strenuous 1

Somewhat strenuous 2

Strenuous 3

Very strenuous 4

27. Out of every 10 emergency calls, on approximately how many calls do you perform **JOB 2**?

Less than 1 call in every 10 1

1-2 calls out of every 10 2

3-4 calls out of every 10 3

5-6 calls out of every 10 4

7-8 calls out of every 10 5

9-10 calls out of every 10 6

28. How physically strenuous is **JOB 2** for you?

Not strenuous 1

Somewhat strenuous 2

Strenuous 3

Very strenuous 4

Task 8: **Two workers** carry a patient in a **stair chair** down a straight line of steps.

This task is part of carrying a patient downstairs in a stair chair. The construction of the stairway permits use of a stair chair, but the weight of the patient and stair chair is being carried by only two workers. In this task, the workers are moving down the section of stairway that is a straight line of steps. There are two separate jobs in this task.

JOB 1. Worker 1 is in the higher position on the stairs, going forward down the stairs.

JOB 2. Worker 2 is in the lower position on the stairs, going backward down the stairs.

29. Out of every 10 emergency calls, on approximately how many calls do you perform **JOB 1**?

Less than 1 call in every 10 1

1-2 calls out of every 10 2

3-4 calls out of every 10 3

5-6 calls out of every 10 4

7-8 calls out of every 10 5

9-10 calls out of every 10 6

30. How physically strenuous is **JOB 1** for you?

Not strenuous 1

Somewhat strenuous 2

Strenuous 3

Very strenuous 4

31. Out of every 10 emergency calls, on approximately how many calls do you perform **JOB 2**?

Less than 1 call in every 10 1

1-2 calls out of every 10 2

3-4 calls out of every 10 3

5-6 calls out of every 10 4

7-8 calls out of every 10 5

9-10 calls out of every 10 6

32. How physically strenuous is **JOB 2** for you?

Not strenuous 1

Somewhat strenuous 2

Strenuous 3

Very strenuous 4

Task 9: **Four workers** carry a patient in a **stair chair** down a straight line of steps.

This task is part of carrying a patient downstairs in a stair chair. The construction of the stairway permits use of a stair chair and allows the weight of the patient and stair chair to be carried by four workers. In this task, the workers are moving down the section of stairway that is a straight line of steps. There are two separate jobs in this task.

JOB 1. These two workers are holding the upper part of the stair chair.

JOB 2. These two workers are holding the lower part of the stair chair.

33. Out of every 10 emergency calls, on approximately how many calls do you perform **JOB 1**?

Less than 1 call in every 10 1

1-2 calls out of every 10 2

3-4 calls out of every 10 3

5-6 calls out of every 10 4

7-8 calls out of every 10 5

9-10 calls out of every 10 6

34. How physically strenuous is **JOB 1** for you?

Not strenuous 1

Somewhat strenuous 2

Strenuous 3

Very strenuous 4

35. Out of every 10 emergency calls, on approximately how many calls do you perform **JOB 2**?

Less than 1 call in every 10 1

1-2 calls out of every 10 2

3-4 calls out of every 10 3

5-6 calls out of every 10 4

7-8 calls out of every 10 5

9-10 calls out of every 10 6

36. How physically strenuous is **JOB 2** for you?

Not strenuous 1

Somewhat strenuous 2

Strenuous 3

Very strenuous 4

Task 10: **Two workers** carry a patient on a **stretcher** down a straight line of steps.

This task is part of carrying a patient downstairs on a stretcher. The construction of the stairway permits use of a full-size stretcher, but the weight of the patient and stretcher is being carried by only two workers. In this task, the workers are moving down the section of stairway that is a straight line of steps. There are two separate jobs in this task.

JOB 1. Worker 1 is in the higher position on the stairs, going forward down the stairs.

JOB 2. Worker 2 is in the lower position on the stairs, going backward down the stairs.

37. Out of every 10 emergency calls, on approximately how many calls do you perform **JOB 1**?

Less than 1 call in every 10 1

1-2 calls out of every 10 2

3-4 calls out of every 10 3

5-6 calls out of every 10 4

7-8 calls out of every 10 5

9-10 calls out of every 10 6

38. How physically strenuous is **JOB 1** for you?

Not strenuous 1

Somewhat strenuous 2

Strenuous 3

Very strenuous 4

39. Out of every 10 emergency calls, on approximately how many calls do you perform **JOB 2**?

Less than 1 call in every 10 1

1-2 calls out of every 10 2

3-4 calls out of every 10 3

5-6 calls out of every 10 4

7-8 calls out of every 10 5

9-10 calls out of every 10 6

40. How physically strenuous is **JOB 2** for you?

Not strenuous 1

Somewhat strenuous 2

Strenuous 3

Very strenuous 4

Task 11: **Two workers** transfer a patient from a stretcher to a hospital gurney using **sheets**.

When the ambulance arrives at the hospital, the stretcher is placed alongside a hospital gurney. Worker 1 stands at the side of the stretcher, Worker 2 stands at the side of the gurney. Each grasps the sheet under the patient with two hands and lifts and shifts the patient toward and onto the gurney. (The patient is not on a backboard.) There are two jobs in this task.

JOB 1. Worker 1, standing beside the stretcher, lifts the patient away from the stretcher and toward the gurney.

JOB 2. Worker 2, standing beside the gurney, lifts and pulls the patient toward and onto the gurney.

41. Out of every 10 emergency calls, on approximately how many calls do you perform **JOB 1**?

Less than 1 call in every 10 1

1-2 calls out of every 10 2

3-4 calls out of every 10 3

5-6 calls out of every 10 4

7-8 calls out of every 10 5

9-10 calls out of every 10 6

42. How physically strenuous is **JOB 1** for you?

Not strenuous 1

Somewhat strenuous 2

Strenuous 3

Very strenuous 4

43. Out of every 10 emergency calls, on approximately how many calls do you perform **JOB 2**?

Less than 1 call in every 10 1

1-2 calls out of every 10 2

3-4 calls out of every 10 3

5-6 calls out of every 10 4

7-8 calls out of every 10 5

9-10 calls out of every 10 6

44. How physically strenuous is **JOB 2** for YOU?

Not strenuous 1

Somewhat strenuous 2

Strenuous 3

Very strenuous 4

NOW WE WOULD LIKE TO ASK YOU A FEW BACKGROUND QUESTIONS.

45. What is your current age?

21 to 29 years old 1

30 to 39 years old 2

40 to 49 years old 3

50 to 59 years old 4

60 years old or older 5

46. How many total years of experience do you have doing fire service, ambulance, or rescue work? (Include both paid and volunteer experience.)

Less than one year 1

1 to 5 years 2

6 to 10 years 3

11 to 15 years 4

16 to 20 years 5

More than 20 years 6

47a. Have you permanently changed your method for doing any of your EMS tasks because of aches, pain, or discomfort?

Yes 1

No . . . . . 2 --> (SKIP TO Q.48a)

47b. Where have you experienced aches, pain, or discomfort that caused you to permanently change your work method(s)? (CIRCLE ALL THAT APPLY.)

Neck 1

Shoulders 2

Elbows 3

Wrists/hands 4

Upper back 5

Lower back 6

Hips/thighs 7

Knees 8

Ankles/feet 9

Other (SPECIFY)_____

48a. Are you currently experiencing any aches, pains, or discomfort?

Yes 1

No . . . . . 2 --> (SKIP TO Q.49)

48b. Where are you currently experiencing any aches, pains, or discomfort? (CIRCLE ALL THAT APPLY.)

Neck 1

Shoulders 2

Elbows 3

Wrists/hands 4

Upper back 5

Lower back 6

Hips/thighs 7

Knees 8

Ankles/feet 9

Other (SPECIFY) _____

49. Do you have any other concerns or comments related to musculoskeletal injuries on the job?

THANK YOU FOR YOUR PARTICIPATION.

Please return your completed questionnaire in the enclosed envelope to:

Lynn Hamilton
Project Coordinator
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Survey Research Laboratory MC 036
910 W. Van Buren, Suite 500
Chicago, IL 60607

QUESTIONNAIRE NUMBER _____

STUDY NUMBER 761

COMPONENT MS

DEPARTMENT _____

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15. Supplementary Notes

16. Abstract (Limit: 200 words) The objective of this study was to describe the frequently performed strenuous emergency medical service tasks that place firefighter/paramedics (FF/Ps) at risk for musculoskeletal injury and to hypothesize ways in which this risk can be reduced. The study group included 542 FF/Ps from 14 suburban fire departments. An initial list of tasks was identified through structured interviews with 29 FF/Ps. A list of the 11 most frequent and strenuous tasks identified in the interviews was validated through a mail survey returned by 374 FF/Ps. The five more frequently performed strenuous tasks identified were simulated, and the working postures and the forces applied by the workers were recorded and described. Each task was simulated and video data were used to determine gross postures and movement ranges. The biomechanical stresses were analyzed and the relative risk of low back disorder was quantified. The lower back disorder risk analysis identified the task components that contribute the most to the development of cumulative trauma back injuries. The strength limitation calculation indicated the task components during which musculoskeletal overexertion injuries were most likely to occur. The spine compression calculations indicated the task components during which disc related back injuries were most likely to occur. Several equipment modifications were suggested as being possible ways of reducing the risk of musculoskeletal injuries during frequently performed, strenuous tasks.

17. Document Analysis a. Descriptors

b. Identifiers/Open-Ended Terms

NIOSH-Publication, NIOSH-Grant, Grant-Number-R03-OH-03123, End-Date-09-29-1996, Musculoskeletal-system-disorders, Firemen, Back-injuries, Accident-prevention, Risk-factors, Epidemiology, Cumulative-trauma-disorders

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