

FINAL PROGRESS REPORT

**Designing Ergonomic Interventions for the Fire Service
(NIOSH Grant Number 1 R01 OH07490)
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List of Abbreviations

EMG—Electromyography
EMS—Emergency Medical Services
EMT—Emergency Medical Technician
FFP—Firefighter/Paramedic
LMM—Lumbar Motion Monitor
SBIR—Small Business Innovation Research

Abstract

Occupational Safety and Health Issue Addressed. Musculoskeletal injuries consistently account for about half of all injuries to firefighter/paramedics engaged in emergency medical services (EMS) operations as well as to EMS workers in the private sector. These injuries result in lost work time, permanent disability, and high worker compensation costs. The tasks performed during EMS runs that place these workers at risk for serious sprain and strain injuries include lifting and carrying patients for transport to the hospital. This problem becomes more serious as the population becomes more obese and the weight of the load increases. In previous research conducted by us with funding from NIOSH, we identified and quantified the most high-risk EMS job tasks in need of ergonomic intervention. These tasks involved transporting patients down stairs and lateral patient transfers.

Purpose of the Study. The purpose of this NIOSH-funded study was to design, build, and evaluate EMS ergonomic interventions that reduce biomechanical loads on the back and are considered worthy of adoption for use by firefighter/paramedics who transport patients during EMS operations. We used a participatory ergonomic process, engaging fire chiefs and firefighter/paramedics throughout the study. The goal of our work is to translate the product of this research into practice.

Methods and Findings by Phase of Study. In Phase 1 of this four-phase study, we conducted focus groups with firefighter/paramedics to generate concept ideas for EMS patient handling devices and task method changes to address the problematic job tasks identified in our earlier research. The focus group participants specified the criteria for what would be considered a useable product and brainstormed concepts while an industrial designer sketched their ideas. Of the 20 concepts generated, the voted top 10 were considered in the following phase. In Phase 2 of the study, prototype EMS devices were produced by us, acquired from inventors, or purchased and modified. Lab testing of simulated stair-descent and lateral transfer tasks was conducted in Phase 3 with 11 two-person teams of firefighter/paramedics. Measures included levels of muscle use (EMG for 8 trunk muscles), heart rate, spine postures and movements, and ratings of perceived exertion. In this phase, we used a repeated measures experimental design to examine the relative effectiveness of new EMS devices compared to the existing approaches in reducing biomechanical loads. The sequencing of the experiments was randomized for each team, as was the sequencing of the experimental versus control condition. Five EMS devices that we designed showed positive EMG results, as did 2 prototype devices acquired from other inventors. One device and a task method change showed either non-significant changes or increases in muscle activity. Results for other outcome measures showed similar patterns to the EMG results. In Phase 4 we pursued commercialization opportunities for those EMS devices that we designed and that showed a biomechanical advantage in our lab tests. We gathered stakeholder input during feedback meetings at the engineering facility as production-ready devices were being developed. Finally, we obtained continuing stakeholder input during this phase as we conducted focus groups to gather information on how to facilitate dissemination and adoption of new EMS devices into practice.

How the Findings Advance the Research. Other than the work we have conducted, little research exists documenting the specific job tasks that pose risk for serious musculoskeletal injury associated with EMS transport of patients. Our research suggests ergonomic interventions that may help reduce the risk of injury to this worker population and offers ideas and suggestions for further research.

How the Results can be Utilized in the Workplace. By sharing our results with the end-users and pursuing the commercialization of the promising EMS devices that we designed, we hope to have a direct impact on reducing the risk for musculoskeletal injury in our target population. Unlike health care workers in an institutional setting, firefighter/paramedics and other EMS workers work in an uncontrolled environment where engineering controls are less feasible. Finding simple, ergonomically designed EMS devices that can be stowed in a small space on an ambulance, are affordable, are quick to assemble, and easy to carry and clean are features identified as essential by this public safety services group. Our EMS devices were developed with these criteria in mind. Recently, the university entered into a licensing agreement with an engineering firm to produce four of the five devices developed during this research project (Backboard Footstrap, Bridgeboard, Transfer Rod, and Transfer Sling).

Highlights/Significant Findings

The long-term goal of our research program is to reduce the high incidence of musculoskeletal injury associated with EMS patient handling tasks. In achieving the overall goal of this project, the study accomplished the following specific aims:

- In conjunction with fire service and other EMS personnel, developed specific equipment design concepts and work method interventions that address ergonomic concerns during emergency medical/rescue service operations.
- Developed and built prototype equipment and refined work methods based on the design process.
- Tested equipment and refined work methods interventions in a biomechanics laboratory setting using simulated EMS tasks. Refined and re-tested equipment and methods as necessary based on participant feedback and biomechanical results.
- Assessed the potential for diffusion, dissemination, implementation, and sustainability of our interventions among end-users involved in EMS operations.

The ultimate product of our research grant is the creation of four new EMS devices (Backboard Footstrap, Bridgeboard, Transfer Rod, and Transfer Sling) for facilitating patient transfer and transport that are biomechanically sound, reasonably priced, and desired by the end-users. The university recently signed a licensing agreement with an engineering firm to produce these four EMS devices. The timeline for this includes early 2007 pre-production runs leading to final design approval and full production and sale by summer 2007. A fifth patient handling device, the Backboard Wheeler, will be the focus of a planned SBIR Phase 1 submission to NIOSH with the engineering firm as the grantee and the research team as collaborators.

An important result of this project is that it has clearly demonstrated the value of collaborating closely with the workers who do the job throughout the entire process of developing solutions to workplace safety issues, in our case the high incidence of musculoskeletal injury associated with EMS patient handling tasks. Because of the continuing involvement of the EMS workers from solution generation through device design, testing, and refinement, we were able to develop patient handling devices that reduce biomechanical loads on EMS workers' backs and are considered worthy of adoption for use by EMS personnel responsible for the transfer and transport of patients during EMS operations.

Additional significant findings resulting from our close collaboration with the fire service and EMS community include:

1. a set of validated design criteria for new EMS devices,
2. an understanding of the important factors that influence purchasing decisions, and
3. delineation of the factors that facilitate the adoption and sustained use of new EMS devices or act as barriers to their use.

Translation of Findings

Given that the primary outcome of this research project is the development of five patient handling devices designed to protect EMS workers from musculoskeletal injuries, the obvious recommendation for reducing hazards during EMS operations is to implement and sustain the use of the devices in practice. These devices are:

1. biomechanically sound in that they reduce the forces required to perform the patient handling tasks such as by changing a lifting task to a pulling task,
2. cost effective, and
3. desirable to the EMS workers who have been intimately involved in their creation as solutions to demonstrated workplace hazards.

Four of the five devices will be available for purchase and implementation in the near future. The fifth device, while demonstrating biomechanical advantage over the existing approaches, requires further engineering. This last device will be the focus of a planned SBIR grant submission.

The translation of research findings to reduce workplace injuries should implement the search for solutions as a collaboration between occupational health experts and the workers themselves. No one knows the job better than the workers who perform it and are thus in an excellent position to help in the creation of solutions, including the specification of criteria for acceptable and useful solutions given the constraints of the job to be performed.

Outcomes/Relevance/Impact

The major outcome of this project is the development of five biomechanically validated patient handling devices designed to protect EMS workers from the high incidence of musculoskeletal injuries that they currently experience. (Four of the devices are in the process of being manufactured. The fifth device requires further engineering and will be the focus of a planned SBIR grant submission.) These injuries result in lost work time, permanent disability, and high worker compensation costs. Given the recent trend toward increasing obesity in the population, it is reasonable to expect that if protective devices are not implemented in the workplace EMS workers will be placed at even greater risk for injury. Unlike health care workers in an institutional setting, firefighter/paramedics and other EMS personnel work in a much less controlled environment where engineering controls are difficult to implement. Finding simple, ergonomically designed EMS devices that can be stowed in a small space on an ambulance, are affordable, are quick to assemble, and easy to carry and clean are features identified as essential by this public safety services group. Our EMS devices were developed with these criteria in mind in order to have maximal impact on the identified occupational health problem.

Scientific Report

BACKGROUND AND SIGNIFICANCE

Sprains, strains, and muscular pain account for over half of the injuries suffered by firefighter/paramedics (FFPs) while performing non-fire emergency tasks, such as emergency medical services (EMS) (Karter & Molis, 2006). This is not unexpected given that today, the majority of fire department calls are for EMS rather than fire suppression. In 2005, 62% of fire department calls were for medical aid with the numbers increasing steadily over time from about 6 million EMS calls in 1986 to over 14 million in 2005 (National Fire Protection Association [NFPA] (Karter & Molis, 2006). The same injury profile holds true for EMS workers in the private sector, such as paramedics working for ambulance companies where in 2004, of the 5170 injuries reported, 3410 of them (67%) were sprain/strain injuries (United States Bureau of Labor Statistics, 2006a). These injuries are typically due to overexertion type activities with the back being the major body part affected (Maguire, Hunting, Guidotti, & Smith, 2005; United States Bureau of Labor Statistics, 2006b; Walton, Conrad, Furner, & Samo, 2003).

These injuries are both costly economically due to high worker compensation costs (Walton, Conrad, Furner, & Samo, 2003) and personally due to permanent disability and premature retirement (Conrad, Balch, Reichelt, Muran, & Oh, 1994). In our analysis of firefighter injuries we found that the overexertion related injuries were associated with high worker compensation costs. More specifically, the overall average claim for worker compensation cost of injury to firefighters was \$5,168 while the mean cost for overexertion related injuries was \$9,715. In medical costs alone, the per claim average was \$1,973 overall compared to \$3,458 for overexertion related injuries. This same analysis showed that 42% of the overexertion injuries affected the lower back. Thus, the prevalence, costs, and disability associated with work-related musculoskeletal injuries among EMS workers, particularly to the back, support the need for analysis and control measures.

While EMS workers do a variety of tasks, a survey by Conrad, Reichelt, Lavender, and Meyer (2000) indicated that the most frequently performed strenuous work tasks entail either lifting and carrying patients down stairs or performing lateral transfers of patients at the emergency location and at the hospital. In addition to the authors (Lavender, Conrad, Reichelt, Johnson, & Meyer, 2000; Lavender, Conrad, Reichelt, Meyer, & Johnson, 2000), others have described the physical demands required by these tasks (Doormaal, Driessen, Landeweerd, & Drost, 1995; Furber, Moore, Williamson, & Barry, 1997; Massad, Gambin, & Duval, 2000). The physical demands continue to increase as the degree of obesity in the population grows. In summary, the EMS worker's tasks involve lifting and carrying heavy loads and assuming awkward body postures while bending and twisting.

There is a recognized need for effective ergonomic interventions to improve worker health (Westgaard & Winkel, 1997). Engineering changes, such as the design of new EMS assistive devices, and task method redesign are two potential intervention avenues for combating musculoskeletal injuries among firefighter/paramedics. Engaging the end-users, who are the experts on their job experience, throughout all phases of an intervention process helps increase the likelihood of program effectiveness (Kogi, 2006; Zalk, 2001). Our research project employed this participatory approach to both generate and evaluate ergonomic intervention ideas for EMS equipment and task redesign.

The purpose of our research grant was to take the next step in the intervention development process. We utilized a user-centered design process, much like what has been advocated by NIOSH (Cohen, Gjessing, Fine, Bernard, & McGlothlin, 1997). In this effort we involved the end-users of the interventions, the FFPs, throughout the process. This allowed us to complete the intervention process that was initiated with our previous study. The significance of this work is that interventions were developed that address the biomechanical concerns of the over one million firefighters and paramedics performing emergency rescue tasks in this country alone. Our research furthers NIOSH's National Occupational Research Agenda (NORA) priority area of low back disorders and addresses the *Healthy People 2010* Occupational Safety and Health Objective 20.3: to reduce the rate of injury and illness cases involving days away from work due to overexertion or repetitive motion.

SPECIFIC AIMS

The long-term goal of our research program is to reduce the high incidence of musculoskeletal injury associated with EMS patient handling tasks. In achieving the overall goal of this project, the study addressed the following specific aims:

Phase 1: In conjunction with fire service personnel, develop specific equipment design concepts and work method interventions that address ergonomic concerns during emergency medical/rescue service operations.

Phase 2: Develop and build prototype equipment and refine work methods based on the design process.

Phase 3: Test equipment and refined work methods interventions in a biomechanics laboratory setting using simulated EMS tasks. Refine and re-test equipment and methods as necessary based on participant feedback and biomechanical results.

Phase 4: Assess the potential for diffusion, dissemination, implementation, and sustainability of our interventions among end-users involved in EMS operations.

METHODS AND RESULTS BY PHASE OF STUDY

Our preliminary ergonomic study had shown the need for equipment modifications and refinement of work methods (Conrad, Reichelt, Lavender, & Meyer, 2000). Given that the simulated tasks in that study were selected based upon a combination of physical strenuousness and perceived high frequency ratings, the interventions developed through the process outlined in this report address the tasks that regularly occur. The intervention development and evaluation process we used was comprised of four phases. In the first phase, the design phase, we worked with FFPs (the end-users) to bring out ideas for equipment modifications and work method refinement based upon the intervention opportunities identified in our previous research. It is during this phase that the specific interventions were identified. In the second phase, the interventions that require the fabrication of equipment were built. The third phase tested the new equipment and work methods in a laboratory environment to quantify the effects on tissue loading. The fourth and final phase was an assessment of the potential for the diffusion and implementation of the interventions among EMS workers. The four phases outlined above correspond with the specific aims of the project. The specific content of each phase is discussed below and further detail is available in the referenced publications.

Phase 1 Design

Specific Aim 1: In conjunction with fire service personnel, develop specific equipment design concepts and work method interventions that address ergonomic concerns during emergency medical/rescue service operations.

Our previous work identified numerous biomechanical concerns in the emergency medical/rescue tasks that could potentially be alleviated through ergonomic interventions. In order to take the next step and fully develop interventions that both address the identified concerns and are considered workable by FFP personnel, a joint design effort between our team and participating fire departments was utilized. This phase of the project used focus group methodology and was completed in three steps. In the first step we conducted 3 paired sets of focus groups, each comprised of 8 or 9 FFPs. Although we brought a good working knowledge of the relevant biomechanical issues based upon our research using simulated tasks, we realized that we did not have the hands-on field experience to fully appreciate how interventions being proposed would affect the FFP job. The in-depth interactions that occurred in these three focus groups of EMS personnel provided this important information. The product of this first step was a list of potentially workable interventions in the form of new equipment ideas and modifications. No recommended changes in work methods separate from equipment changes were developed. In the second step, using the data from this initial design step, our industrial designer produced drawings that visually presented the concepts developed in the focus groups. Because these drawings would guide the development of the

ergonomic interventions, the third and final step in Phase 1 was to re-convene the focus groups for the purpose of confirming that the drawings accurately reflected the FFPs' input into the design process.

Participants. The focus groups were comprised of volunteers recruited from the fire departments in the Chicago suburbs that partnered with us in this endeavor. These departments include both union and non-union work environments. We opted to work with suburban, as opposed to urban, fire departments since most firefighters in these fire departments are currently cross-trained as paramedics because (in concert with the national trend) the majority of their calls are for emergency medical/rescue services rather than for fire suppression. The Fire Chiefs Steering Committee of IRMA (the Intergovernmental Risk Management Agency, which provides the fire departments with worker compensation insurance) served as a valuable advisory panel and communications link between the investigators and the participating fire departments.

Each focus group consisted of 8 or 9 individuals for a total of 25 FFPs representing 13 different fire departments so that we achieved a wide experience base and minimized social inhibitions that may exist if all the members of a focus group belong to the same department. Ninety-two percent (n=23) of the participants were male, 96% (n=24) were white and the remaining one participant was African American. The mean age of the group was 37 years (range 25-52 years). The mean number of years of experience performing EMS operations was 13 years (range 2-28 years). This distribution reflects the ethnic composition of our study population.

Procedure. Three paired sets of focus groups were conducted. Each focus group member participated in two rounds of focus groups (termed Focus Group A and Focus Group B) each lasting two hours in length. There was a 100% retention rate with no dropouts between the first and second paired sessions.

Three typical patient transport devices identified in our earlier research (Conrad, Reichelt, Lavender, & Meyer, 2000); namely, a stretcher, a stairchair, and a backboard, were available to be used as props for the participants to demonstrate work postures. Video footage and still camera photos were taken of participants as they demonstrated work postures. The sessions were audiotaped and later transcribed verbatim. Following the initial focus groups (Focus Group A), an industrial designer, who was present for all of the focus groups, produced sketches that visually presented the concepts developed by the participants. The sketches were presented for review at the second focus group (Focus Group B). A note taker summarized key points. In generating concept ideas, participants were asked to address issues of perceived effort, feasibility, adoption, and economic impact.

In the first round of focus group sessions (Focus Group A), participants were asked open-ended questions to get their ideas for new devices/equipment and work method approaches that they thought could reduce musculoskeletal problems related to EMS operations. Separate discussion guides were created for the initial and second round of focus groups to direct the conversations. Participants were presented with an EMS patient transport/transfer job task drawn from our earlier research that identified and quantified the biomechanical risk of the most frequently performed, physically strenuous EMS patient transfer/transport tasks (Conrad, Reichelt, Lavender, & Meyer, 2000). Job tasks discussed in the focus groups included: transport down stairs, lateral transfers from a bed to a backboard, stretcher, or gurney, and transfer of a patient from a seated position to a stairchair.

To start the discussion flowing, the participants were asked to describe situational factors to be considered when performing the exemplar task. Next, the participants were asked to describe a typical piece of equipment or method they would use in that particular case. They brought up the conditions that posed injury risk given the task, the situation, and the selected piece of equipment. Once this preliminary contextual scenario was created, the group started brainstorming about potential solutions. In coming up with an ergonomic solution, participants were encouraged to offer varying views and perspectives. As solutions were expressed, the group further developed them. At this point the emphasis was on creating a broad range of ideas; usability issues were secondary.

In the second round of focus group sessions (Focus Group B), the participants reconvened with their original group members. Using the data from the initial round of focus groups, the purpose of the second round of focus groups was to have the participants refine the intervention concepts by addressing usability issues. This

second round of sessions began by having the participants confirm that the industrial designer's sketches accurately reflected their ideas. As usability issues were discussed, sketches of each concept were refined as necessary. Following the focus group discussion, participants completed a brief demographic questionnaire and were compensated for their participation.

Product. The discussions of the ideas for new devices often included some evaluative comments beyond the baseline one of making the firefighter/paramedic's job easier while not adversely impacting the patient. Thematic analysis of these comments quickly revealed a set of commonly held end-user criteria for new patient-handling devices that if attained would make the device desirable and likely to be adopted by EMS workers. These criteria are:

- Affordable,
- Easily stowed on the ambulance,
- Quickly ready for use, including any necessary assembly,
- Easily cleaned and disinfected,
- No easily broken or lost parts.

In all, 20 concept ideas were generated. The ideas clustered around the following types of devices: backboard accessory devices, stairchairs, lateral assistive devices, bed-to-stairchair assistive devices, and jump-kit (i.e., medical supply bag) accessories. The focus groups generated a lot of thoughtful discussion where participants freely offered ideas and often "played the devil's advocate" in reacting to one another's suggestions. The product was a rich, detailed list of ideas for new EMS devices.

Upon completion of the focus groups, the research team reviewed all 20 concept ideas and reduced the number to 16 based on ergonomic considerations, current product availability, and the generated end-user criteria. These remaining concepts were presented at a subsequent stakeholders' meeting where participants voted for their top choices. The top 10 concepts were then developed for the lab-testing phase of the study. Thus, the focus groups generated viable ideas for design solutions for EMS devices. As suggested by Langford and McDonagh (2003), the focus groups were a useful method for identifying desirable and undesirable product features.

The focus groups also provided an opportunity to learn about the contextual issues that affect patient transfer/transport and that need to be considered in developing design solutions. While there was variability among the fire departments represented in terms of which EMS device may be preferred in a given job task scenario, there was considerable consistency in what constituted desirable design features for the EMS devices. The end-user acceptance criteria developed in the focus groups has continued to serve as a guidepost for product development.

The product of Phase 1 is further discussed in the following manuscript:

Conrad, K.M., Reichelt, P.A., Lavender, S.A., Gacki-Smith, J., & Hattle, S. (submitted for publication). Designing ergonomic interventions for EMS workers: Concept generation of patient handling devices.

Phase 2 Build and Refine	Specific Aim 2: Develop and build prototype equipment and refine work methods based on the design process.
↓	The information obtained from the two rounds of focus groups was used to create final versions of the intervention drawings for the non-commercially available interventions. These drawings provided the basis for the construction of modified or new equipment, i.e., EMS devices.

Development and Acquisition of Prototypes. The development and building of the prototype EMS devices was done by the Scientific Instrument Shop of the University of Illinois at Chicago and by outside contractors. These prototypes are primarily completely new devices and to a lesser extent modifications of currently used equipment. As the equipment was completed, we arranged demonstrations with EMS personnel from the

cooperating fire departments. The purpose of these demonstrations was to obtain feedback from the personnel who will actually use the equipment so that refinements could be made to the prototype equipment prior to biomechanical testing. Following these sessions, the feedback and suggestions were compiled and the necessary modifications made to the prototype equipment.

Product. The research team developed five EMS devices; two prototype devices were acquired from other inventors; and one device was special ordered from a manufacturer. More specifically, the EMS devices, developed in the Phase 2 prototype development process were:

- Down the stairs—a footstrap to prevent the patient from sliding down on the backboard, a change in the handle configuration on the stairchair, and two devices, the backboard wheeler and a tank-tread like device (Descent Control System™ [DCS]) for a stretcher, that change the backboard and stretcher carrying tasks into rolling and gliding tasks.
- Lateral transfer—a bridgeboard to reduce the frictional force resisting the lateral sliding of the patient, the use of rods along each side of the patient to facilitate the grasping and handling of the bed sheet on which the patient is typically transferred, and a single rod that, when rolled in the bed sheet, results in the task being changed from a lifting task to a pulling task.
- Bed to stairchair—a prototype Drew People Mover™, and a transfer sling.

Once the prototype devices were ready, an instructional videotape was prepared for each prototype that demonstrates how the equipment should be used. We used a team of FFPs that was involved in the design process to serve as the demonstrators in this training video.

Phase 3
Laboratory
Testing

Specific Aim 3: Test equipment interventions in a biomechanics laboratory setting using simulated EMS tasks. Refine and re-test equipment as necessary based on participant feedback and biomechanical results.

Once the prototype EMS devices were developed in Phase 2, laboratory testing was conducted in our Fire Service Ergonomics Laboratory to assess the biomechanical impact of the ergonomic changes. The purpose of the Phase 3 laboratory work was to test ergonomic interventions aimed at reducing the low-back musculoskeletal loads experienced by firefighter/paramedics providing emergency medical services when: transporting patients down the stairs, performing lateral patient transfers between a bed and a stretcher or between a stretcher and a hospital gurney, and when transferring a patient between a bed and a stairchair. This Phase 3 testing evaluated whether the proposed interventions reduced the biomechanical loading of the spine and the postural loads on the upper and lower extremities when compared with the equipment currently in use. Thus, the experiments described in this phase were focused on quantifying the working postures of the torso and the extremities, the dynamic three-dimensional spine moments, and the muscle activation levels that can be anticipated to occur in real emergency rescue situations through implementation of the proposed interventions.

The EMS devices tested in Phase 3 along with a description of the biomechanical rationale for each are as follows:

- Down the stairs—a footstrap to prevent the patient from sliding down on the backboard thereby keeping the horizontal distance between the spine and the handles (moment arm) as small as possible; a change in the handle configuration on the stairchair to reduce the bending and the reach distance for the FFP carrying the upper part of the chair which supports the patient's torso and head; and two devices, the backboard wheeler and a tank-tread like device (Descent Control System™ [DCS]) for a stretcher, that change the backboard and stretcher carrying tasks into rolling and gliding tasks thereby reducing the force applied by the FFPs.
- Lateral transfer—a bridgeboard to reduce the frictional force resisting the lateral sliding of the patient, the use of rods along each side of the patient to facilitate the grasping and handling of the bed sheet on which the patient is typically transferred, and a single rod that, when rolled in the bed sheet, results in the task being changed from a lifting task to a pulling task.

- Bed to stairchair—a prototype Drew People Mover™, and a transfer sling. The transfer sling was tested using both a two-person and a one-person transfer. These interventions change the coupling between the EMS worker and the patient and in so doing were expected to reduce the amount of forward bending required at the initiation of the lift. They were compared with the commonly used under-axilla lift.

Participants. Given that our previous study determined that most of the more physically demanding tasks performed by FFPs (for example transferring, lifting, and carrying victims) are typically performed in two-person teams, we recruited 11 two-person teams of FFPs from fire departments in the Chicago suburbs to serve as the participants in these tests. All participants were employed fulltime as FFPs at their respective departments. Each participant signed an informed consent prior to participating in the study. Ten of the teams were comprised of two males. One team was comprised of two females. Assignment to a specific team was based on availability. Similar to actual work situations, the team members designated which FFP would perform the single-person transfers in addition to which role each would take on during the two-person transfers. The mean age, height, and weight of the subjects was 37 years (28 to 51 years), 1.80 m (1.63 to 1.89 m), and 96 kg (70 to 123 kg), respectively. All the participants were white except for 1 African American male. On average the FFPs had 12 years of experience in the EMS component of the job (<1 to 25 years). None were experiencing low back pain at the time of the study. The participants were compensated for their participation in the data collection sessions.

Procedure. The experiment used a randomized block design wherein each team served as a block and experienced all the interventions in a randomized sequence. Each intervention was compared to the type of equipment currently used to perform the patient transfer or transport.

The primary dependent measures were the surface electromyographic (EMG) signals from 8 trunk muscles recorded from each FFP. The muscles sampled included the left and right Latissimus Dorsi (LATL and LATR), Erector Spinae (ERSL and ERSR), External Oblique (EXOL and EXOR) and Rectus Abdominus (RABL and RABR). After normalizing each muscle relative to a maximal contraction, the mean and 90th percentile level of each muscle's activity was extracted for analysis.

In addition to the EMG recordings, the subjects were instrumented to obtain three-dimensional measures of torso motion and, for the FFP performing the single-person lifts and lifting the patient's right side in the two-person lateral transfers, the external three-dimensional trunk moments at L5/S1. The FFP performing the single-person lifts was instrumented with magnetic sensors (Accension) on each shank, each thigh, the pelvis (S1), and at the top of the thorax (T1). The FFP connected to the magnetic sensors stood on two Bertec forceplates. The FFP performing only the two-person transfers was instrumented with a Lumbar Motion Monitor (LMM) to quantify trunk postures. When performing the downstairs transport tasks both FFPs were instrumented with LMMs. For all tests each FFP was connected to an eight channel telemetered EMG system (Noraxon). The RMS output from the Noraxon amplifiers was sampled along with the kinematic and kinetic data using InnSport™ Motion Monitor data collection software at 120 Hz for 6 seconds.

In each transfer task a 75 kg dummy, similar to one used by the fire service for training exercises, was moved. For the seated transfer tasks, a strap was used to keep the dummy in the seated posture throughout the transfer. For the transport tasks, the dummy was secured to the apparatus using standard patient strapping methods.

After reading and signing the informed consent documents and watching an instructional video that demonstrated how to use the experimental interventions, each member of the team was instrumented with disposable surface electrodes (Cleartrace™ 1700-030) at standard muscle sites as described by Marras (1987). For the Erector Spinae, the electrodes were positioned approximately 5 cm lateral from the midline at the L3 level. The Latissimus Dorsi electrodes were positioned at the T7 level over the belly of the muscle, approximately 13 to 15 cm lateral from the midline. The External Oblique electrodes were positioned at the level of the umbilicus and centered approximately halfway between the iliac crest and the anterior superior iliac spine at an angle of 45°. The Rectus Abdominus electrodes were placed just above the umbilicus approximately 2.5 cm lateral from the midline.

Prior to conducting the study, the subjects performed two types of maximal voluntary exertions to obtain maximal EMG signals for normalization purposes. In the trunk extension exertions subjects pulled up on a handle positioned at approximately mid thigh level. This resulted in a modest degree of spine flexion (~ 20°), similar to what we expected during the more strenuous points in the task. This task was repeated until maximal EMG values were obtained from both the Erector Spinae and Latissimus Dorsi muscles. The trunk flexion exertions were completed by connecting a cable between a chest harness and a reference frame apparatus (Lavender, Tsuang, Andersson, Hafezi, & Shin, 1992). These provided maximal signals from both sets of abdominal muscles. In reality, because of the weight of the dummy, often these “maximal” values were exceeded during the testing protocol. When this occurred, the maximal values were replaced with the highest observed EMG value from the experimental trials. This occurred for approximately half the muscles sampled, but varied considerably across subjects.

Prior to collecting data for each exertion, the team members positioned themselves for the transfer according to the prescribed conditions. The team was in charge of coordinating the timing of each transfer. During each task, the FFPs were encouraged to verbally communicate with each other as they typically would on the job. Immediately after the completion of each exertion the subjects were asked to provide a rating of perceived exertion using the Borg CR10 (Borg, 1998). The team was given a one to two minute rest period as the data were checked, and while members of the research staff positioned the dummy in preparation for the next experimental condition.

After the completion of each team’s data collection session, we asked the participants to describe any refinements they believed necessary to make the prototype interventions more usable given the constraints they face when performing emergency medical/rescue tasks.

Data Analysis. The EMG readings were normalized to relative maximum and resting levels. The kinetic and kinematic data for the FFP on the force plates were used in a linked-segment biomechanical model that calculated the L5/S1 moments by working up from the ground reaction force data through the ankles, knees, and hips. The model has been described previously (Lavender, Shakeel, Andersson, & Thomas, 2000). For each lateral transfer exertion, the 90th percentile value from each muscle’s normalized EMG data and the 90th percentile value from each moment direction were extracted from the data. For the down the stairs transport tasks the mean values of the EMG activation across the multi-second task were also analyzed. It was these 90th percentile and mean values for these variables that were subsequently analyzed using the statistical analysis described below.

The EMG data from each FFP, the spine moment data from the right-side FFP and the spine kinematic data were analyzed using the PROC GLM (analyses of variance) in the SAS software (version 8.0). Where significant effects ($p < .05$) were found in the two-person test, the REGWQ multiple comparison procedure was used, as it controls the experiment-wise error rate, to make comparisons between the intervention conditions tested. The ratings of perceived exertion (RPE) data were analyzed using the SPSS (version 11.5) Wilcoxon signed ranks test and the Friedman Tests for the one and two person transfers, respectively.

Product. Results for down the stairs showed that the backboard footstrap reduced the Erector Spinae (ERS) activity for the FFP in the “leader” role by 15 percent, on average. The change in handle configuration on the stairchair had no effect on the variables measured. The backboard wheeler reduced the ERS activity bilaterally in the FFP in the leader role and unilaterally for the FFP in the “follower” role, by 28 and 24 percent respectively. The DCS reduced the 90th percentile ERS activity for both FFPs from 26 to 16 percent MVC, but increased the Latissimus Dorsi activity in the follower from 11 to 15 percent MVC. The Descent Control System was the only intervention tested that resulted in a reduced rating of perceived exertion relative to the corresponding control condition.

During the lateral transfers, trunk flexion moments and Erector Spinae activity were reduced for the FFP in the stretcher-side role when using the bridgeboard and the single rod both individually and in combination. The single rod reduced the Erector Spinae activity in the FFP who typically would have been on the bed. For FFPs in both roles, the single rod increased Latissimus Dorsi activation relative to the standard bed sheet transfer condition

although this effect was moderated when the single rod was used in combination with the bridgeboard. Ratings of perceived exertion also supported the use of the single rod relative to the corresponding control condition. The use of two rods did not reduce the muscle activations relative to the corresponding control condition.

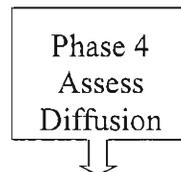
For the bed to stairchair two-person transfers, there was 19 degrees less trunk flexion ($p=.002$) for the FFP on the patient's *left* side and a trend towards less motion for the FFP on the patient's *right* side ($p=.079$) when using the interventions. Both FFPs showed reductions in the ipsilateral Erector Spinae activity using the Drew People Mover™ and the transfer sling that averaged approximately 9 percent MVC, which corresponds to a 21 percent decrease in the muscle activation levels. While the overall EMG was greater when performing a single-FFP transfer, the transfer sling reduced the bilateral Erector Spinae activity by approximately 20 percent. During the two-person transfers, the FFP on the forceplate to the right side of the patient showed a reduction in the forward bending moment using the Drew People Mover™ relative to the sling and under axilla conditions. For the single-person transfers, only the twisting moment was significantly reduced through use of the transfer sling. These objective measures, when combined with the subjective ratings of perceived exertion and the verbal feedback lead us to recommend the use of these interventions for bed to stairchair transfers.

The full results of all of the Phase 3 laboratory testing are discussed in the following three published papers included as part of this Final Progress Report:

Lavender, S.A., Conrad, K.M., Reichelt, P. A., Gacki-Smith, J., & Kohok, A.K. (2007). Designing ergonomic interventions for EMS workers, Part I: Transporting patients down the stairs. *Applied Ergonomics*, 38, 71-81.

Lavender, S.A., Conrad, K.M., Reichelt, P. A., Kohok, A. K., & Gacki-Smith, J. (2007). Designing ergonomic interventions for EMS workers--part II: Lateral transfers. *Applied Ergonomics*, 38, 227-236.

Lavender, S.A., Conrad, K.M., Reichelt, P. A., Kohok, A.K., & Gacki-Smith, J. (in press). Designing ergonomic interventions for emergency medical services workers--part III: Bed to stairchair transfers. *Applied Ergonomics*.



Specific Aim 4: Assess the potential for diffusion, dissemination, implementation, and sustainability of our interventions among end-users involved in EMS operations.

At this point in the study, we have a set of EMS patient handling devices that have withstood the test of biomechanical validation in Phase 3. Phase 4 was the implementation and evaluation phase of our intervention study and it is focused on the five most promising prototypes developed during this project for down-the-stairs patient transport and lateral patient transfers.

Down-the-Stairs Transport

- Backboard Footstrap
- Backboard Wheeler

Lateral Transfers

- Bridgeboard
- Transfer Rods
- Transfer Sling

We know that having demonstrated the intervention effectiveness of our devices in Phase 3 does not by itself assure that the EMS community will embrace them, even though they have partnered with us from the inception. We need to actively facilitate “research to practice.” Consistent with our views, NIOSH researchers Stout and Lin (2002) recently noted that “occupational injury prevention researchers need to take more responsibility, and more action, to understand and affect the transfer and adoption of our research and prevention knowledge and products by those whose health and lives we strive to protect. This is our most immediate barrier and challenge”

(Page iv). To this end, we began Phase 4 by planning for the implementation and dissemination of four of the five prototypes. The Backboard Wheeler is not part of Phase 4 because it is the most complex device and will require additional resources to develop its potential for EMS practice. Current plans are to collaborate with our engineering contractor to submit an SBIR proposal to NIOSH to commercialize the Backboard Wheeler.

In Phase 4 we again worked with our fire service and EMS stakeholders to explore the commercialization potential of the four EMS patient handling devices by:

1. examining how purchasing decisions are made,
2. exploring factors that may influence adoption of new EMS devices, and
3. obtaining stakeholder feedback during the re-engineering process.

Each of these topics is discussed in turn.

Purchasing Decisions

Participants. Three fire departments and two private ambulance companies were selected for interviews about the EMS equipment purchasing process using purposive sampling to maximize the variability in the EMS situations where the devices might be used. In each case, the person who was interviewed had major responsibility for the EMS equipment purchasing process for the organization. The organizations selected were a major urban fire department, a large suburban fire department, a small rural volunteer fire department, a large urban/suburban ambulance company, and a statewide risk management company that included a large medical transportation unit.

Product. As would be expected from the sampling procedure used, the five organizations had substantially different organizational structures, procedural steps and budgets for making purchases, and patterns of internal communications. However, there were some major similarities in how the EMS equipment purchasing process was conducted. In regard to how organizations became aware of new equipment on the market, unsolicited catalogs and calls from unknown sales representatives did not receive much attention. Greater reliance was placed on contacts from companies the organizations already did business with, from presentations and displays at educational workshops and conventions, and recommendations from colleagues in other fire departments and ambulance companies.

Although again varying greatly in the details, all the organizations were also similar in having procedures for field-testing new equipment prior to purchase and for obtaining input from their EMTs and paramedics who are performing EMS services. There seemed to be consensus that although younger staff with fewer years of practicing in specific ways tended to be more open to new equipment and ways of performing tasks, all staff members were interested in new equipment that was demonstrably superior to current equipment.

Once new equipment was purchased, all organizations engaged in a training process to make sure that the EMS workers were proficient in its use. Practice policies for the use of the equipment were formulated, and were typically written for easy reference. One interviewee mentioned that the best way to make sure that the new equipment was consistently used was to remove the old equipment it replaced from the ambulances.

Adoption Potential of New EMS Devices

The purpose of our Phase 4 focus groups was to gather information on how best to facilitate the dissemination and adoption of new EMS devices into practice. This segment of our final phase addressed the following research question: What worker factors, workplace factors, and external environmental factors influence the adoption of new EMS patient handling devices such as those designed in this study?

Participants. In addressing this research question we conducted five focus groups with a total of 42 firefighter/paramedic participants from 26 fire departments and one private ambulance company. Two of the fire departments contracted for EMS services from private ambulance companies. Ninety-one percent of the

participants were male. Ninety-one percent were White with the remainder Black, Hispanic, or Asian. The participants' mean age was 38 years (range 22-55). Twelve percent were at the rank of Captain or higher; 19% were Lieutenants, and the remainder were either line duty firefighter/paramedics or EMTs. One of the focus groups was comprised of officers only. The Discussion Guide for the focus groups was drawn from a theoretical model that we developed based on a review of the following theories/models: Social Marketing Theory, Technology Acceptance Model, Diffusion of Innovation, Health Promotion Model, Social Cognitive Theory, and PRECEDE-PROCEED Theory.

Product. A manuscript based on the focus group findings is in preparation. We highlight a few of the preliminary findings here. Participants said factors that attracted them to new EMS devices were safety, including saving one's back, reliability, durability, credibility based on feedback from other departments, seeing a device used in the field, cost, good customer service, brand recognition, accessibility in emergency situation, ease of use, and recommendation from the EMS medical community and department risk management agencies. Barriers to use include factors like price, practicality, complaints from firefighter/paramedics, difficulty storing on ambulance, poor quality, and being too cumbersome to carry. The mind set on the job is to work fast – speed is a factor. This makes training on a device essential. We also learned that departments become aware of “smaller type” devices in a variety of ways such as “word-of-mouth,” catalogs, websites, conferences, neighboring departments, emails, newsletters, and EMS meetings. Culture affects willingness to try innovations. Participants shared with us how the culture in the departments is changing in that they are not as steeped in tradition as they once were. They remarked that EMS, in particular, is not very culture laden. Participants felt that younger workers are often open to trying new things. They thought that if an EMS device was introduced during EMT training, this would likely influence its adoption on the job. EMS coordinating hospitals and insurance carriers influence purchase decisions too. Participants offered ideas for instructional material content. They offered suggestions for how to get the “nay sayers” on board such as offering demonstrations to the departments with ease of implementation a key.

Stakeholder Feedback

Participants. The testing prototypes constructed for use in our Fire Service Ergonomics Laboratory are basically “proof of concept” devices that allowed us to determine which devices were biomechanically advantageous for the provision of EMS services. In order to move these devices toward mass production commercial viability, we worked with our engineering contractor to carry out a necessary re-engineering process that examined such things as functional capabilities, materials options, and manufacturing methods. To make sure that this re-engineering process remained true to the Phase 3 testing prototypes and the Phase 1 criteria for new EMS devices, we invited our fire service and private sector EMS stakeholders to provide feedback as the process progressed. Organizationally mixed groups of EMS personnel met with the investigators and the professional engineering staff at the engineering facility to review and provide feedback about the evolutionary changes being made to the devices and to generate suggestions for further improvements.

Product. The feedback from these group sessions validated the criteria for new EMS devices generated by the Phase I focus groups, which were:

- Affordable,
- Easily stowed on the ambulance,
- Quickly ready for use, including any necessary assembly,
- Easily cleaned and disinfected,
- No easily broken or lost parts.

The discussions amplified these criteria such as quickly ready to use including both ease of use and amount of effort required. It also became clear that for a new device to be deemed acceptable to EMS workers (and therefore a device that they want to adopt) it must reduce the amount of effort currently required to perform the patient transfer or transport task, and that it must not have the potential to compromise either the workers' or the patients' safety. The discussions generated useful suggestions for refinements of the four new devices, including the

visibility and visual appeal of the devices and elimination of design aspects that could limit the use of a device or allow it to be used in an unintended and unsafe manner.

The ultimate product of our research grant is the creation of four new EMS devices for facilitating patient transfer and transport that are biomechanically sound, reasonably priced, and desired by the end-users. The university recently signed a licensing agreement with an engineering firm to produce these four EMS devices. The timeline for this includes early 2007 pre-production runs leading to final design approval and full production and sale by summer 2007. As previously noted, a fifth device, the Backboard Wheeler, will be the focus of a planned SBIR Phase 1 submission to NIOSH with the engineering firm as the grantee and the research team as collaborators.

Publications

The following manuscript presents the data collected to accomplish the Phase 1 specific aim:
In conjunction with fire service personnel, develop specific equipment design concepts and work method interventions that address ergonomic concerns during emergency medical/rescue service operations.

Conrad, K.M., Reichelt, P.A., Lavender, S.A., Gacki-Smith, J., & Hattle, S. (submitted for publication). Designing ergonomic interventions for EMS workers: Concept generation of patient handling devices.

The following three publications present the data collected to accomplish the Phase 3 specific aim:
Test equipment and refined work methods interventions in a biomechanics laboratory setting using simulated EMS tasks. Refine and re-test equipment and methods as necessary based on participant feedback and biomechanical results.

Lavender, S.A., Conrad, K.M., Reichelt, P. A., Gacki-Smith, J., & Kohok, A.K. (2007). Designing ergonomic interventions for EMS workers, Part I: Transporting patients down the stairs. *Applied Ergonomics*, 38, 71-81.

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Lavender, S.A., Conrad, K.M., Reichelt, P. A., Kohok, A.K., & Gacki-Smith, J. (in press). Designing ergonomic interventions for emergency medical services workers--part III: Bed to stairchair transfers. *Applied Ergonomics*.

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Principal Investigator/Program Director (Last, First, Middle): Conrad, Karen, Maria

Inclusion Enrollment Report

This report format should NOT be used for data collection from study participants.

Study Title: Designing Ergonomic Interventions for the Fire Service
 Total Enrollment: 96 Protocol Number: _____
 Grant Number: NIOSH 1 R01 OH07490

PART A. TOTAL ENROLLMENT REPORT: Number of Subjects Enrolled to Date (Cumulative) by Ethnicity and Race				
Ethnic Category	Sex/Gender			Total
	Females	Males	Unknown or Not Reported	
Hispanic or Latino		2		2 **
Not Hispanic or Latino	8	80		88
Unknown (individuals not reporting ethnicity)	1	5		6
Ethnic Category: Total of All Subjects*	9	87		96 *
Racial Categories				
American Indian/Alaska Native		1		1
Asian		1		1
Native Hawaiian or Other Pacific Islander				
Black or African American		3		3
White	8	77		85
More Than One Race				
Unknown or Not Reported	1	5		6
Racial Categories: Total of All Subjects*				96 *
PART B. HISPANIC ENROLLMENT REPORT: Number of Hispanics or Latinos Enrolled to Date (Cumulative)				
Racial Categories	Females	Males	Unknown or Not Reported	Total
American Indian or Alaska Native				
Asian				
Native Hawaiian or Other Pacific Islander				
Black or African American				
White		2		2
More Than One Race				
Unknown or Not Reported				

Racial Categories: Total of Hispanics or Latinos**		2		2 **
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* These totals must agree.

** These totals must agree.