FINAL PROGRESS REPORT

ERGONOMIC INTREVENTIONS FOR COMMERCIAL FISHERMEN

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LIST OF TERMS AND ABBREVIATIONS

3DSSPP – University of Michigan #-D Static Strength Prediction Program
ANOVA - Analysis of Variance
CABS – Continuous Assessment of Back Stress
CI – Confidence Interval
CLR – Confidence Limit Ratio
EMG - Electromyography / Electromyographic
GEE - Generalized Estimating Equations
IEMG - Integrated Electromyographic Signal
LAB – Left Rectus Abdominis
LAD – Left Anterior Deltoid
LBP - Low Back Pain
LES - Left Erector Spinae
LMM - Lumbar Motion Monitor
LPD - Left Posterior Deltoid
MANOVA – Multiple Analysis of Variance.
MSD - Musculoskeletal Disorder
MVE - Maximum Voluntary Exertion
MVC – Maximum Voluntary Contraction
NIEMG - Normalized Integrated Electromyographic Signal
NIOSHLE – NIOSH Lifting Equation
PATH - Posture, Activity, Tools and Handling
PHRGM – Probability of High Risk Group Membership
RAB – Right Rectus Abdominis
RAD – Right Anterior Deltoid
RES - Right Erector Spinae
RPD - Right Posterior Deltoid
RR – Rate Ratio
NS - Not Significant
SE – Standard Error

ABSTRACT

The specific aims of this project were to study the effectiveness and the efficacy of ergonomic interventions for the reduction of musculoskeletal injuries/illnesses in the commercial crab fishing industry and, more generally, to explore some of the unique ergonomic and/or biomechanical challenges faced by workers in this industry. This research effort can be broken down into five research projects that were completed during the period of this grant. The aim of Project #1 was to identify those jobs and work tasks that were most problematic from the perspective of musculoskeletal injury/illness. This was accomplished through surveys and interviews of commercial fishermen. The result of this structured analysis was a list of jobs/work tasks prioritized in terms of numbers and severity of musculoskeletal injury/illness risk. The aim of Project #2 was to identify the specific physical risk factors posed by these work tasks jobs. This process involved video analysis of these work activities wherein the physical stressors were documented. The result of this video task analysis process was a detailed description of the physical exposures (forces, postures, repetition rates, exposure to vibration, etc.). The aim of Project #3 was to design, engineer and prototype engineering and work practice controls with the expressed goal of eliminating or reducing exposure to the identified risk factors. This process was often an iterative process that involved both lab testing (see Project #4 below) as well as feedback from fishermen (see Project #5 below). The aim of Project #4 was to perform a formal laboratory analysis of the prototypes developed through Project #3. Project #4 involved the use of bioinstrumentation (electromyography, electrogoniometry, magnetic-based motion analysis systems) to precisely quantify the impact of the prototyped interventions on the risk factors that the prototypes were designed to address. The result of this structured, formal, biomechanical analysis of these prototypes was quantitative information with regard to the prototype that 1) illustrated that the prototype was ready for a formal field assessment (Project #5) or 2) the prototype could/should be re-engineered and re-prototyped to arrive at a design that is able to further reduce exposure to the identified risk factors. The aim of Project #5 was to perform a field analysis of the prototypes developed through Project #3 and assessed in Project #4. This process involved a subjective assessment of the design by commercial crab fishermen.

SECTION 1.

HIGHLIGHTS/SIGNIFICANT FINDINGS

The specific aim of this project was to study the effectiveness and the efficacy of ergonomic interventions for the reduction of work-related musculoskeletal disorders in workers in the commercial crab fishing industry.

As a result of the formal survey and interviews conducted, four on-boat and three on-land work activities were identified as likely to contribute to the risk of musculoskeletal problems faced by these fishermen:

- ➔ Hooking Buoy (shoulder)
- ➔ Lifting Crab Pot (low back)
- ➔ Shaking Crab Pot (shoulders and low back)
- ➔ Sorting Crabs (low back)
- ➔ Loading Bait onto Boat (low back)
- ➔ Unloading Catch from Boat (low back)
- ➔ Cleaning Crab Pots (low back)

A formal task analysis designed to identify the specific risk factors encountered in these high risk jobs. An iterative prototyping process was employed that generated a total of 12 ergonomic interventions for these different work tasks. Through a process of laboratory evaluation and industry feedback, this set of interventions was reduced to a set of four that went through a formal laboratory evaluation to assess the impact of the intervention on the levels of exposure to identified risk factors and four that went through a formal field evaluation to assess their impact in realistic work environments.

The laboratory evaluation confirmed the effectiveness of the interventions in reducing exposure to the specific identified risk factors. A modified method proposed for the **hook buoy** task resulted in a 46% (50% of max vs. 27% of max) reduction in the peak normalized EMG of the right anterior deltoid and a 24% (45% of max vs. 34% of max) reduction in the peak normalized EMG of the right posterior deltoid muscle. The ergonomic intervention developed to reduce the low back stress during the **lift crab pot** task generated a 45% (74 degrees vs. 41 degrees) reduction in peak sagittal angle and a 23% (48% of max vs. 37% of max) reduction in normalized EMG of the erector spinae muscle group. The modified method proposed for the **shake crab pot** task resulted in a 52% (33% of max vs. 16% of max) reduction in the peak normalized EMG of the erector spinae muscle group and a 24% (37% of max vs. 26% of max) reduction in the peak normalized EMG of the right posterior deltoid muscle. The intervention developed for the reduction in low back stress during the **crab sorting** task showed a 27% (110 degrees vs. 76 degrees) reduction in the peak sagittal flexion angle

The field evaluation of the interventions supported the findings of the laboratory evaluations on the impact on exposure to the identified risk factors and provided additional insight into the utility of the individual interventions. Specifically, the fishermen provided detailed insight as to how these devices should be modified to be useful in different crab fishing scenarios / strategies as well as how they could be modified to fit the variety of on-boat workplace configurations used by one-, two- or three-man fishing crews. They further added that these interventions would be particularly useful to older fishermen that have lost some of their strength and dexterity.

TRANSLATION OF FINDINGS

It is generally held that engineering controls offer the greatest hope of reducing the incidence of musculoskeletal disorders in the workplace. The commercial fishing industry is a particularly challenging industry because of the natural environment in which the work is performed. Work tasks performed by these workers involve exposure to many of the recognized risk factors for work-related musculoskeletal disorders and lead to high rates of injury/illness to the proximal upper extremity and low back. In this project we developed and tested several ergonomic interventions for reducing the physical stress on these fishermen. These interventions included a ramp system that allows the crab pots to be pulled up from the water to a location near the fishermen at about mid-torso level, thereby eliminating the need for the fishermen to bend over the side of the boat to retrieve the crab pots. The second intervention was a type of boom that mounted on the side of the boat. This boom had a pair of suspended hooks and as the fisherman lifted the pot from the water he could hang the crab pot from the hooks. This intervention eliminated the need for the fisherman to support the weight of the crab pot as they were shaking the crabs from the pot onto the sorting table. The third intervention was a false bottom work surface for sorting the crabs. This work surface is approximately 30 cm higher than the bottom of the typical crab box. By putting this false-bottom shelf on top of the crab box the static posture assumed by the fisherman is significantly improved avoiding static fatigue in their low back. The fourth intervention was a change in the work method employed by the fisherman, in this case the captain. As the captain is reaching to grab the bout with the catch pole, he was encouraged to use a hand-over-hand method to retrieve the bout to the boat side. This change in work method resulted in a significant reduction in the awkwardness of the shoulder posture when the bout was up to the side of the boat. The fifth intervention was a crab pot washing system. It was quickly recognized that the weight of the crab pots was increased significantly by the attachment of barnacles. A pressure washer system was designed to allow the fisherman to place the pot in the chamber and let the pressure washer clean the pots while he was doing something else. The interventions described here are outlined in more detail in the Scientific Report section of this manuscript and can be built by a fisherman to modify their work task and reduce musculoskeletal stress.

OUTCOMES/RELEVANCE/IMPACT

The outcomes of this work are ergonomic interventions that have been shown to reduce the loading on the musculoskeletal system while fishermen perform the work activities of commercial crab fishing. Results of this work have shown significant reductions in the stresses in the low back and shoulder regions while performing these tasks. These interventions were also tested by commercial fishermen and feedback from these end users was incorporated when developing the final interventions.

SECTION 2.

SCIENTIFIC REPORT

SPECIFIC AIMS

The objectives of this proposed intervention research are to develop and implement ergonomic controls (simple engineering controls, advanced engineering controls, and administrative controls) for commercial crab fishing operations and then to evaluate the efficacy and effectiveness of these interventions. To achieve these objectives, the following are specific aims:

1. To perform an assessment to determine the operations and tasks that pose the greatest ergonomic risks in commercial crab fishing operations (as determined by numbers of exposed workers and/or by severity of injuries/symptoms), based upon data collected in a previous study and additional interviews with fishermen.

2. To develop a profile of the biomechanical demands of the high risk work activities through the use of existing ergonomic and biomechanical analysis tools and a stochastic model of hazard assessment where appropriate.

3. To design, develop, evaluate and implement controls designed to reduce biomechanical stress during operations/task performance, as well as occurrence and severity of symptoms of work-related musculoskeletal disorders.

4. To evaluate the efficacy of these controls by comparing the post-intervention biomechanical stress with the pre-intervention biomechanical stress in a sample of crab fishermen performing each redesigned operation or task.

The remainder of Section 2 of this report is a series of stand-alone papers that describe the work done to achieve each of these specific aims. Each of these papers will provide the background, methods, results, discussion and conclusions for that particular project. Most of these are either published or currently in review and the citations are provided at the end of Section 2.

SPECIFIC AIM #1: IDENTIFICATION OF HIGH RISK OPERATIONS/TASKS

AIM #1; PAPER #1

TITLE: Ergonomic Risk Factors for Low Back Pain in North Carolina Crab Pot and Gill Net Commercial Fishermen

ABSTRACT

Background The objective of this research was to determine the association between LBP that limited or interrupted fishing work and ergonomic low back stress measured by (1) self-reported task and (2) two ergonomic assessment methods of low back stress.
Methods Eligible participants were from a cohort of North Carolina commercial fishermen followed for LBP in regular clinic visits from 1999 to 2001 (n=177). Work history, including crab pot and gill net fishing task frequency, was evaluated in a telephone questionnaire (n= 105). Ergonomic exposures were measured in previous study of 25 fishermen using two methods. The occurrence rate of LBP that limited or interrupted fishing work since last visit (severe LBP) was evaluated in a generalized Poisson regression model.
***Results** Predictors of severe LBP included fishing with crew members and a previous history of severe LBP. Among crab pot and gill net fishermen (n= 89), running pullers or net reels, sorting catch, and unloading catch were associated with an increased rate of LBP. Percent of time in forces >20 lb while in non-neutral trunk posture, spine compression >3,400 N, and National Institute of Occupational Safety and Health lifting indices >3.0 were associated with LBP.*
Conclusions Tasks characterized by higher (unloading boat and sorting catch) and lower (running puller or net reel) ergonomic low back stress were associated with the occurrence of severe LBP. History of LBP, addition of crew members, and self-selection out of tasks were likely important contributors to the patterns of low back stress and outcomes we observed. Based on the results of this study, a participatory ergonomic intervention study is currently being conducted to develop tools and equipment to decrease low back stress in commercial crab pot fishing.

INTRODUCTION

Back pain is a common occupational problem in commercial fishermen. In a cross-sectional study of Swedish deep-sea fishermen, half of fishermen experienced low back symptoms during the last 12 months [Torner et al., 1988a]. Low back symptoms were the most common cause of work impairment among a cohort of North Carolina commercial fishermen [Lipscomb et al., 2004]. Risk factors for the prevalence of low back symptoms include age, length of time in the occupation, type of fishing and gear, job title, and fishing part-time, or working more than one job [Torner et al., 1988a; Lipscomb et al., 2004]. However, the importance of these factors from a prevention standpoint is limited by the degree to which they are modifiable. Little is known regarding the relationship of LBP with specific fishing tasks, their frequency. or their duration. It has been previously documented that fishermen perform strenuous tasks [Torner et al., 1988a; Lipscomb et al., 2004; McDonald et al., 2004], and ergonomic studies have evaluated biomechanical low back stress for fishing tasks [Torner et al., 1988b; Fulmer and Buchholz, 2002; Mirka et al., 2005; Kucera et al., 2008]. However, no study has evaluated specific tasks and ergonomic measures as risk factors for low back pain in a population of fishermen.

Previous studies have described characteristics of fishing work such as static, awkward working postures, shoveling and lifting tasks, which produce strain to the low back area [Torner et al., 1988a; Lipscomb et al., 2004; McDonald et al., 2004]. Ergonomic analyses of commercial fishing crews revealed that work tasks were repetitive and cyclic with high-intensity lifts during loading and unloading activities [Torner et al., 1988b; Fulmer and Buchholz, 2002; Mirka et al., 2005; Kucera et al., 2008]. More specifically, low back stress varied by the type of fishing performed, size of the crew, job, and task performed [Kucera et al., 2008]. While certain job characteristics may produce low back stress, their association with low back pain in fishermen is undetermined.

The objective of this research was to determine the association between low back stress and low back pain that limited or interrupted fishing work. Low back stress was measured by (1) self-reported task and (2) the percent of time exposed to low back stress (measured with two ergonomic assessment methods). A secondary objective was to examine the influence of other covariates such as previous history of severe LBP, age, and years fishing experience. Our study population was a group of southeastern US commercial fishermen who fished with crab pots and gill nets in small-scale, independent operations on coastal or inland waters.

MATERIALS AND METHODS

Study Population

Participants in this study were members of a cohort of commercial fishermen originally assembled during the period of April 1999 to May 2000 for the purpose of studying exposure to a toxic marine micro-organism [Moe et al., 2001]. This population included licensed commercial fishermen 18–65 years of age who fished on inland rivers and sounds or on the ocean for at least 20 hr per week for at least 6 months of the year. Individuals completed self-administered questionnaires at baseline and at 6-month intervals during medical clinic visits for a period of up to 2 years. Information was gathered on the presence of musculoskeletal pain, traumatic injuries, and fishing activities and other exposures. In addition to regular visits, fishermen were encouraged to come in for "trigger" visits defined by conditions relating to exposure to toxic micro-organisms (e.g., skin lesions, memory loss, cognitive impairment) or if they were exposed to diseased fish [Moe et al., 2001]. Fishermen were also interviewed every 1–2 weeks by phone from August 1999 to May 2002 about work-related injuries, fishing activities, and other exposures of interest. Injury data from clinic visits and follow-up of the cohort have previously been reported [Lipscomb et al., 2004; Marshall et al., 2004].

A Supplemental Questionnaire was administered by telephone in April of 2004 to retrospectively assess more details on fishing and non-fishing work exposures and whether they performed specific fishing tasks. Of 177 fishermen available for interview, we were unable to reach 60 participants (contact number not available, n=27, and unable to reach, n=33); of those we did reach, 106/117 agreed to participate. Note: we use the term fisherman because that is how the participants, men and women, referred to themselves and to others. The University of North Carolina at Chapel Hill School of Public Health Institutional Review Board approved all study procedures and all subjects provided written informed consent prior to participation.

Low Back Pain

A revised version of the Nordic Musculoskeletal Questionnaire [Kuorinka et al., 1987] was administered in all clinic exams to determine the presence and severity of LBP at baseline and subsequent follow-up visits. Reliability of the instrument ranges from 77% to 100% and validity, compared to clinical history, ranges from 80% to 100%. Information collected included 12-month prevalence of low back pain at baseline and occurrence of LBP since last clinic visit. For both baseline and follow-up clinic visits, participants were asked if this low back pain limited work (reduced work level or tasks) or interfered with work (unable to work for a day or more) and, if so, how long they were unable to work. For this study, severe LBP was defined as any reported LBP that limited or interfered with normal fishing work activity. We could not determine whether reports of LBP at follow-up were new or recurrent, therefore we consider all occurrences of LBP in this study.

Fishing Exposure

During the follow-up clinic visits fishermen reported the fishing methods (e.g., pots, gill nets, trawl, dredge) and type of catch (crab, finfish, shrimp, clam, oyster, or other) since last visit. In weekly (April–October) and biweekly (November–March) telephone interviews, the fishermen reported the type of catch, number of days spent on and off the water, and estimated the number of hours they spent on the water for the most recent day fishing. Detailed exposure information was gathered in the supplemental questionnaire for crab pot and gill net fishermen and included the frequency respondents performed specific fishing tasks (e.g., driving the boat, pulling in gear, unloading boat). A Likert rating scale (1–5) quantified the frequency of task performance: never, less than half the time but more than never, half the time, more than half the time but less than always, or every time/ everyday. This scale was dichotomized for analysis as follows: if fishermen performed a particular task during the study period on average "more than half the time" or "always," then they were considered exposed to that self-reported task.

Ergonomic Exposure Assessment

In a previous study, ergonomic exposure to low back stress was measured in a purposive sample of 25 commercial crab pot and gill net fishermen using two ergonomic assessment methods appropriate for non-routine work [Kucera et al., 2008]. Researchers observed and videotaped fishing work, both on and off the water, for a full day. Video tapes were coded for each fisherman using two different methods.

The first method, a work sampling based method, Posture, Activity, Tools, and Handling (PATH) [Buchholz et al., 1996], linked work tasks and activities with posture codes to estimate the percent of time workers spent in various situations stressful to the low back. Cut points were established from previous occupational studies. Non-neutral trunk postures [Punnett et al., 1991; Burdorf and Sorock, 1997], lifting 44.5 N (4.5 kg) at least once per minute [Punnett et al., 1991], and material handling tasks [Riihimaki, 1991; Burdorf and Sorock, 1997] have been identified as risk factors for low back pain. The percent of time fishermen were observed in low back stress was quantified for three PATH measures: percent of time in non-neutral trunk postures (trunk flexion >208, lateral bend and twist >208), percent of time handling loads or exerting force >20 lb (9 kg), and percent of time performing manual materials handling tasks (defined as lifting, lowering, carrying, holding, and pushing or pulling boxes, crates, baskets, etc.). The combination of force >20 lb in non-neutral trunk postures was examined to capture the multi-dimensionality of these two measures.

The second method, Continuous Assessment of Back Stress methodology (CABS) [Mirka et al., 2000], utilized three well-established ergonomic assessment methods to evaluate biomechanical stress of occupational activities: the revised National Institute of Occupational Safety and Health Lifting Equation (NIOSHLE) [Waters et al., 1993], the Ohio State University Lumbar Motion Monitor™ (LMM) [Marras et al., 1993], and the University of Michigan Three-Dimensional Static Strength Prediction Program™ (3DSSPP) [Chaffin et al., 1987; Chaffin and Erig, 1991]. Low back compression from 3DSSPP, lifting index from NIOSHLE, and the probability of high-risk group membership from LMM were measured for defined fishing tasks (e.g., driving the boat, pulling in gear) and combined with the estimated time and frequency fishermen were exposed to these tasks. These values were combined to form time– weighted distributions of low back stress.

Compression values >3,400 N have been associated with an increased risk for low back pain among workers [Lavender et al., 1999]. Lifting indices >1.0 have been associated with low back pain, while indices over 3.0 are reported as a potential problem for most workers [Waters et al., 1993, 1999; Lavender et al., 1999]. The percent of time fishermen were exposed to low back stress for these two measures were defined as follows: the percentage of time >3,400 N of spine compression, the percentage of time lifting index >1.0, and the percentage of time lifting index >3.0. Probability of high-risk group membership of 35% or greater has been identified as a problem for industrial workers [Marras et al., 1995]. Because the majority of fishing tasks in this study had >35% probability of high-risk group membership [Kucera et al., 2008], we evaluated a higher cut point of >70% probability of high-risk group membership. This variable quantified the percentage of time fishermen were engaged in fishing tasks in the upper 30% probability of high risk.

Exposure Assignment

At each follow-up period, exposure to low back stress was assigned to participants according to whether they fished with crab pots or gill nets (Table I). If fishermen fished with both methods during the period, they were assigned the fishing task and the higher ergonomic mean by type (crab pot or gill net). If they performed neither crab pot nor gill net fishing during the interval they were assigned a zero.

TABLE I. Fishing Task and Ergonomic Exposure Assignment by Fishing Type Performed During Follow-Up Interval for North Carolina Commercial Fishermen, 1999-2001

Fishing type during follow-up interval	Crab pot	Gill net	Fishing task assignment	PATH or CABS assignment
Crab pot only	Yes	No	Crab pot task	Crab pot value
Gill net only	No	Yes	Gill net task	Gill net value
Crab pot and gill net	Yes	Yes	Crab pot or gill net task	Larger value of crab pot or gill net
Neither	No	No	0	0
Did not respond to task questions	-	-	Excluded	Excluded

Data Analysis

Descriptive statistics were calculated by baseline demographic and work history characteristics as well as by fishing types at follow-up and self-reported job tasks from the supplemental questionnaire. The occurrence rate of severe LBP was modeled using generalized Poisson regression [Rothman and Greenland, 1988] with log person-days at risk included as an offset term. Days at risk were calculated from days between clinic visits. Generalized estimating equations (GEE) [Liang and Zeger, 1986; Zeger and Liang, 1986] were used to account for the statistical dependence between multiple clinic visits and multiple severe LBP occurrences per fisherman. Outcome covariate rate ratios (RR) and 95% confidence intervals (95% CI) were computed from the model and stratified by previous history of severe LBP. Confidence limit ratios (CLR, calculated as the upper confidence limit divided by the lower confidence limit) were produced to quantify precision for all estimates [Poole, 2001]. Non-overlap of stratum-specific confidence intervals indicated heterogeneity by previous severe LBP. Baseline covariates of interest were: gender, age, smoking history, fishing full time (at least 32 hr/ week) or year round (at least 9 months of the year). Follow-up covariates included performing more than one type of fishing during the follow-up interval, fishing type and gear, and average hours per day on the water. Variables of interest from the supplemental questionnaire included years of fishing experience and work exposures during the study such as fishing with crew versus alone and working a non-fishing job during follow-up that required any of the following: frequent bending or twisting at the waist; work in awkward postures; frequent lifting (>3 lifts per minute); and lifting >50 or >25 lb.

For crab pot and gill net fishermen who answered the supplemental questionnaire, we modeled the rate of severe LBP by low back stress exposure measured with self-reported fishing task and PATH and CABS methods. PATH and CABS means were modeled with a multi-level mixed linear model accounting for the variability between and within fishing type, crew size within fishing type, and job type within crew size within fishing type [Kucera et al., 2008]. These means were included in Poisson regression models as continuous variables. The exponentiated parameters represent the change in the rate of severe LBP per 1 unit change in mean percent time exposed to low back stress measures. For example, the increase in the rate of severe LBP going from a peak of 29% of time to 30% of time in non-neutral trunk posture.

RESULTS

Descriptive Statistics

The majority of fishermen who answered the supplemental telephone questionnaire (n= 105) were male and between the ages of 30 and 59 (Table II). All except one were White, non-Hispanic. Most fished at least 32 hr per week for at least 9 months of the year and owned their own boat. Almost half worked another job not related to fishing. At baseline, 61% reported experiencing any LBP in the last 12 months and 24% experienced LBP that limited or interrupted their work in the past 12 months.

The 105 fishermen accumulated 58,143 person-days of follow-up during the study. Crab pot and gill net were the most common type of catch and fishing method reported (Table II).Over40%reportedspending onaverage4–6hron the water their most recent day of fishing. Over follow-up, 61% (64/105) of fishermen reported 132 occurrences of any LBP since the last visit and 26% (27/105) of fishermen reported 40 occurrences of severe LBP. Sixty-eight percent of severe LBP occurrences (27/40) interrupted working activity for at least a day: 52% (14/27) interrupted work 1–7 days, 33% (9/27) 8–30 days, and 15% (4/27) over 30 days. When asked if LBP had ever caused them to change the way they fish, 37% said it had.

Participants began fishing at a young age (Table II). Over half had 20 or more years of experience as a commercial fisherman and most reported being a captain for most of their career. During the study period, the majority of fishermen worked with crew members (68%) and fished with others on a boat they owned (61%). Participants who worked a second non-fishing-related job during the study reported some form of low back stress in that job. Most were required to twist or bend frequently at the waist or lift >25 lb; fewer worked in awkward postures, lifted, repetitively, or lifted >50 lb (Table II).

General Risk Factors for the Occurrence of Severe LBP

The overall crude rate of severe LBP was 0.69 per 1,000 person-days (95% CI 0.47, 0.90) or 0.25 per person-year. Compared to fishermen 40 years of age and older, fishermen 18–29 experienced an increased rate of severe low back pain and fishermen 30–39 experienced a decrease in rate. Current smoking, fishing on someone else's boat, fishing types other than crab or finfish, and fishing full-time were associated with severe LBP (Table III). Fishermen who averaged the fewest and the most hours on the water had higher rate of severe LBP compared to fishermen averaging 0–6 hr on the water. Fishing year round and performing more than one type of fishing during the follow-up interval were not associated with severe LBP.

The occurrence rate of severe LBP decreased as years of fishing experience increased (Table III). Participants who fished during the study with others experienced an increased rate of severe LBP compared to those who fished alone. Workers with non-fishing-related jobs during the study were at decreased rate of severe LBP regardless of whether that job required frequent lifting, twisting, or bending frequently, awkward postures or lifting >25 or >50 lb.

Having a history of severe LBP was strongly associated with subsequent occurrence at follow-up (Table III). Among fishermen with a previous history of severe LBP, smoking, working a non-commercial fishing-related job, and fishing full time were associated with an increased occurrence rate. Among fishermen without a previous history of LBP, increased occurrence rates were observed for fin fishing (specifically gill nets) and performing more than one type fishing.

Table II. Baseline demographic and follow up information for North Carolina commercial fishermen who participated in a supplementary questionnaire (n=105), 1999-2001.

Age	n	%
18 to 21	3	2.9%
22 to 29	8	7.6%
30 to 39	19	18.1%
40 to 49	36	34.3%
50 to 59	28	26.7%
60 to 69	11	10.5%
Mean (SE) Range	46.2 (11.1)	19 to 65
Gender		
Male	87	82.9%
Female	18	17.1%

Smoking History		
Current	39	57.4%
Past	30	44.1%
Never	37	35.2%
Baseline work exposures		
Own a boat	102	97.1%
Work regularly on someone else's boat	20	19.0%
Fish full time (32 or more hours per week)	84	80.0%
Fish year round (9 or more months of the year)	62	59.0%
Since last visit did you fish for…?		
Crab		
With crab pot gear	82	78.1%
Finfish	74	70.5%
With gill net gear	78	74.3%
Shrimp	69	65.7%
Oyster	43	41.0%
Clam	19	18.1%
Other type	23	21.9%
Average hours on the water per day during interview period	26	24.8%
Up to 4 hours		
Over 4 to 6 hours	35	34.0%
Over 6 to 8 hours	42	40.8%
Over 8 to 10 hours	17	16.5%
Over 10	4	3.9%
Missing	5	4.9%
Mean (SE) Range	2	-
Number of clinic visits per person	4.9 (2.2)	1.3 to 11.6
1		
2	105	100%
3	103	98.1%
4 to 6	86	81.9%
Mean (SE) days between follow up visit Range	43	41.0%
	162 (72)	38 to 736
Years as commercial fisherman		
0 to 9 years	6	5.7%
10 to 19 years	21	20.0%
20 to 29 years	32	30.5%
30 to 39 years	30	28.6%
40+ years	16	15.2%
Mean (SE) Range	26.6 (11.5)	3 to 54
Age began fishing		
Mean (SE) Range	19 (12.1)	5 to 54
Self identified job title most often held…		
Captain	80	76.2%

Mate	18	17.1%
Co-captain	7	6.7%
When first starting to fish, did you fish...?		
Alone only	23	21.9%
With crew only	50	47.6%
Alone and with crew	32	30.5%
Work a non-fishing job during the study?		
Yes	47	44.8%
Did that job require you to...?		
Twist or bend frequently	28	59.6%
Work in awkward postures	16	34.0%
Lift repetitively (>3 lifts/min)	10	9.5%
Lift >25 pounds	28	59.6%
Lift >50 pounds	16	34.0%
Total	105	100%

Low Back Stress Measures as Risk Factors

For those who fished with crab pots and gill nets (n= 89), the majority fished alone (crab pots 70% and gill nets 64%). Fishermen reported performing an average of 8.7 (SE 3.7) fishing tasks over half the time (range 1–14). In general, over 90% of fishermen reported loading bait and/or supplies, pulling in, emptying, and setting gear, and cleaning the boat more than half the time (Table IV). Few regularly used a dolly or lift to load and unload their boats. A third operated pullers and net reels. The majority of crab pot fishermen reported baiting pots (83%) and the majority of gill net fishermen iced down catch (84%). Thirty-eight percent of crab pot fishermen helped sort their catch at the fish house or point of sale.

Analysis of self-reported tasks with these 89 crab pot and gill net fishermen (313 visits) indicated that running the puller or net reel, sorting catch on the boat, and unloading catch or supplies with or without mechanical assistance more than half the time were each independently associated with an increased occurrence rate of severe LBP compared to those who performed those tasks half the time or less (Table V). Driving the boat, loading bait and supplies with or Little evidence for dose–response was observed for without mechanical assistance, pulling, emptying or setting the combined number of tasks performed (RR= 1.1, 95% gear, cleaning the boat, and maintenance work more than half CI 0.9, 1.2). Stratifying tasks by potential exposure to low the time were not associated with severe LBP. back stress revealed no difference between static tasks and dynamic tasks: number of static tasks including driving the boat, running the puller or net reel, setting gear, sorting catch on the boat or at the fish house, cleaning or maintenance of boat and gear (RR= 1.2, 95% CI 0.9, 1.5) versus number of dynamic tasks including loading or unloading the boat, using a dolly or lift for loading/unloading, and pulling in or emptying gear (RR= 0.9, 95% CI 0.6, 1.3).

When examining the ergonomic characteristics of the 89 crab pot and gill net fishermen, severe LBP increased with mean percent time exposed to forces >20 lb in non-neutral trunk postures, >3,400 N of spine compression, and lifting index >3.0 (Table VI). The rate of severe LBP was unassociated with non-neutral trunk postures, forces >20 lb, manual materials handling, lifting index >1.0, and probability of high-risk group membership >70%. However, these RR represent an increase in risk per 1 unit increase in the percent of time exposed. An increase from 10% of time to 20% of time (10 unit increase) in the percent of time in non-neutral trunk postures resulted in a RR of 1.40.

TABLE III. Unadjusted Rate Ratios and 95% Confidence Intervals* of Low Back Pain Occurrences That Interrupted or Limited Work for North Carolina Commercial Fishermen (n=105, Visits=358), 1999-2001.

	Severe LBP occurrences	Days at risk	Unadjusted RR† (95% CI)	CLR
Age				
18 to 29	10	5081	2.4 (1.0, 5.8)	6.1
30 to 39	4	10,073	0.6 (0.2, 1.6)	7.6
40+	26	41,989	1.0	
Current smoking	20	21,346	1.8 (0.8, 3.7)	4.6
No	20	36,797	1.0	
Work on someone else's boat	9	10,162	1.5 (0.6, 3.5)	5.8
No	31	47,981	1.0	
Other fishing types	12	25,690	0.6 (0.3, 1.1)	3.7
Crab or finfish	28	32,453	1.0	
Fishing full-time (>=32 hrs/wk)	34	45,995	1.5 (0.6, 4.0)	6.7
Fishing less than full-time	6	12,148	1.0	
Average hours on the water/day[1]				
0 to 6	32	42921	1.0	
>6 to 9	4	10861	0.4 (0.1, 1.5)	15.0
>9	4	3202	1.8 (0.7, 4.4)	6.3
Years fishing experience				
0 to 9	5	3157	2.5 (0.9, 6.9)	7.7
10 to 19	9	11,916	1.2 (0.5, 2.9)	5.8
Over 20	26	43,070	1.0	
Fished with crew 1999 to 2001	32	38,722	2.4 (0.9, 6.2)	6.9
Fished alone 1999 to 2001	8	19,421	1.0	
Non-commercial fishing job				
No	26	32,691	1.0	
Yes	3	6365	0.6 (0.2, 2.6)	13.0
Yes with low back stress[2]	11	19,087	0.7 (0.3, 1.6)	5.3

† Poisson regression estimates are adjusted for multiple visits per subject with GEE
CLR, confidence limit ratio, upper conf limit divided by the lower conf limit [Poole 2001]
[1] Average hours on the water, n=103, visits=352
[2] Low back stress defined as presence of one of the following: twist or bend frequently, work in awkward postures, lift repetitively, lift>25 or >50 pounds.

TABLE IV. All frequencies represent the percentage of fishermen who reported performing that task over half the time

	Among Crab pot n=71	Among Gill net n=55	Total n=89
Drive boat	87%	82%	89%
Load bait and/or supplies	93%	98%	96%
Use dolly or lift to load bait and/or supplies	15%	5%	16%
Pull in gear (hook/pull in pot or pull in net)	90%	95%	94%
Run puller or net reel	37%	20%	33%
Empty gear (shake crab pot or pick fish from net)	83%	96%	93%
Bait crab pot	83%	-	-
Set gear (toss/push pot or run out net or toss net overboard)	86%	85%	90%
Sort catch on the boat	41%	64%	63%
Ice down catch	-	84%	-
Unload catch and/or supplies	87%	91%	89%
Use dolly or lift to unload catch and/or supplies	14%	9%	15%
Sort catch at the fish house	38%	-	-
Clean boat	86%	91%	92%
Perform routine maintenance on boat or gear	77%	84%	81%

Represent all frequencies the percentage of fishermen who reported performing that task over half the time.

TABLE V. Crab Pot and Gill Net Fishermen: Unadjusted Rate Ratios and 95% Confidence Intervals* for the Occurrence of LBP That Interrupted or Limited Work for Self-Reported Fishing Task Frequency (n= 89, 313 Visits)

Severe LBP occurrences		Days at risk	RR* (95%CI)	CLR
Drive boat	29	38,945	1.2 (0.4, 3.4)	7.9
Loading bait or supplies				
Without mechanical assistance	30	42,424	0.9 (0.3, 2.9)	9.6
With mechanical assistance (e.g., dolly or lift)	6	5,959	1.3 (0.4, 4.0)	9.5
Pull in gear (hook/pull in pot or pull in net)	28	40,837	0.9 (0.3, 2.3)	6.9
Run pot puller or net reel	19	14,719	2.5 (1.2, 5.5)	4.7
Empty gear (shake crab pot or pick fish from net)	29	41,061	0.8 (0.3, 2.3)	7.7
Bait crab pot (crab pot only)	26	33,621	1.1 (0.5, 2.4)	4.6
Set gear (toss/push pot or run out net or toss net overboard)	29	39,732	1.0 (0.4, 2.8)	7.4
Sort catch on the boat	23	25,651	1.9 (0.8, 4.3)	5.4
Ice down catch (gill net only)	17	26,035	1.2 (0.6, 2.7)	4.7
Unload catch and/or supplies				
Without mechanical assistance	30	38,987	1.5 (0.5,4.6)	10.1
With mechanical assistance (e.g., dolly or lift)	9	5,799	2.5 (1.1, 5.6)	5.1
Sort catch at the fish house (crab pot only)	13	15,413	1.1 (0.5, 2.7)	5.8
Clean boat	29	40,398	1.0 (0.4, 2.8)	7.9
Perform routine maintenance on boat or gear	28	36,047	1.3 (0.5, 3.3)	6.6

CLR, confidence limit ratio, upper confidence limit divided by the lower confidence limit [Poole, 2001].

Exposed (1): fishermen who perform task over half the time; referent (0): fishermen who perform task half the time or less.

*Poisson regression estimates are adjusted for multiple visits per subject with GEE.

DISCUSSION

In this cohort of small-scale crab pot and gill net fishermen differences were observed in the occurrence of severe LBP by self-reported fishing task (Tables IV and V) and by ergonomic low back stress assessment (Table VI). Operating pullers and net reels, using a dolly or lift to unload catch and supplies, and sorting catch on the boat were strongly associated with severe LBP. Dose–response for task frequency was not observed in this group nor was there a difference observed between static or dynamic tasks. Ergonomic measures associated with the occurrence of severe LBP in this study included forces >20 lb in non-neutral trunk postures and levels of spinal compression >3,400 N and lifting index values >3.

Results for PATH and CABS measures generally supported the independent self-reported task findings. Sorting catch on the boat, a task characterized by static, awkward postures and repetitive motions performed extensively by a mate or third man [Mirka et al., 2005; Kucera et al., 2008], occurred more frequently in larger crew sizes and was associated with severe LBP in this study. Likewise, sorting catch at the fish house, a less stressful task for the low back where fishermen work at tables in upright postures, was not associated with LBP. Unloading catch or supplies, with or without a dolly, was a task characterized by high compression and lifting index values in the ergonomic assessment [Kucera et al., 2008]. We observed an association with severe LBP for this task and high compression and lifting index measures. Previous studies of manual lifting occupations have reported unadjusted associations with any LBP and lifting indices from 1 to 2, 2 to 3, and >3 [Waters et al., 1999].

We did not observe an association for loading activities despite the higher ergonomic low back stress reported by fishermen [McDonald and Kucera, 2007] and described in previous work [Kucera et al., 2008]. Similarly, tasks that are not associated with high ergonomic low back stress, running puller or net reel, were also associated with severe LBP. These results likely reflect differences in task performance by fishing type (e.g., gill net fishermen do not use bait; therefore, have less to load). Differences could also be attributed to age and the addition of crew members which could reflect distribution of tasks between captains and mates as well as self-selection into tasks by age or job or previous LBP. Without specific information regarding task selection and temporality, we were limited in our ability to quantify these potential risks.

We observed age and years of experience were associated with the occurrence of severe LBP. Torner et al. [1988] found higher prevalence of LBP for Swedish fishermen age 41–50 but prevalence decreased thereafter. In addition, fishermen with fewer years experience (20–29 years) had more LBP when compared to those who fished over 40 years [Torner et al., 1988a]. We observed similar results for years experience in our subset population. Like the ocean-going Swedish fishermen, many in this cohort started fishing at young ages. However, the age participants began fishing in the current study ranged from 5 to 54 years. Those who started their career later had fewer years experience, and this could explain why we did not see decreasing occurrence rates with increasing age.

Subjective self-reported work-related causes of low back stress have been reported differently by job. Captains have been reported to attribute low back stress to static work postures (driving and running puller) while mates identified dynamic tasks and postures (shoveling and lifting) [Torner et al., 1988a]. Interviews with North Carolina commercial fishermen indicated that loading and unloading bait and boxes of catch were stressful for the low back [Lipscomb et al., 2004; McDonald et al., 2004; McDonald and Kucera, 2007], and we hypothesized that tasks with higher low back stress measured with PATH and CABS (e.g., loading, unloading, pulling or emptying gear, and sorting on the boat) would be associated with severe LBP. However, we found varying results and suspect this may depend on age, whether crew members were present, or whether other fishing types were performed. These fishermen were largely an independent group of workers and often mediate their exposures in many ways including choice of fishing type, addition of crew, decreasing hours on the water or volume of catch set, or task selection [Lipscomb et al., 2004; McDonald et al., 2004; McDonald and Kucera, 2007].

TABLE VI. Crab Pot and Gill Net Fishermen: Unadjusted Rate Ratios and 95% Confidence Intervals for Mean Percent Time Exposed to Low Back Stress and Low Back Pain Occurrences That Interrupted or Limited Work (n= 89, 313 Visits)

	Fishing type	Percent time exposed to low back stress[1] Mean (se)	Inter-quartile range	Unadjusted Parameter (se)†	Unadjusted RR (95% CI)	CLR
PATH						
Non-neutral trunk posture	Gill net	24.04 (7.58)	14.0	0.0337	1.03 (0.96, 1.11)	1.2
Force > 20 lbs (9 kg)	Gill net	9.78 (3.82)	3.0	0.0820	1.09 (0.92, 1.28)	1.4
	Crab pot	10.93 (2.10)	10.0	(0.0852)		
Handling materials[2]	Gill net	39.16 (7.98)	13.0	0.0079	1.01 (0.98, 1.04)	1.1
	Crab pot	23.91 (5.12)	20.0	(0.0150)		
Non-neutral trunk and force > 20 lbs (9 kg)	Gill net	2.70 (0.99)	2.0	0.2886	1.33 (0.76, 2.36)	3.1
	Crab pot	3.19 (0.57)	3.0	(0.2903)		
CABS						
Spine compres >3.4kN[3]	Gill net	0.54 (2.61)	1.5	0.1591	1.17 (0.91, 1.50)	1.6
	Crab pot	3.79 (1.93)	8.7	(0.1267)		
Lifting Index > 3.0[4]	Gill net	0.09 (1.47)	0.3	0.2448	1.28 (0.87, 1.89)	2.2
	Crab pot	2.25 (1.12)	4.1	(0.1988)		
Lifting Index > 1.0[4]	Gill net	31.14 (11.05)	56.8	0.0133	1.01 (0.97, 1.05)	1.1
	Crab pot	21.67 (7.62)	26.4	(0.0203)		
Prob High Risk > 70%[5]	Gill net	48.76 (9.37)	33.7	0.0166	1.02 (0.98, 1.05)	1.1
	Crab pot	51.94 (6.10)	23.4	(0.0177)		

CLR, confidence limit ratio, upper confidence limit divided by the lower confidence limit [Poole, 2001].

[a]Mean percent time in low back stress measured in sample of fishermen adjusted with multi-level mixed linear model with three nested variables: fish type, crew nested within fish type, job nested within crew within fish type [Kucera et al., 2008].

[b]Poisson regression estimates are adjusted for multiple visits per subject with GEE.

[c]Lift, lower, carry, push/pull, slide, or hold.

[d]Low back compression measured in Newtons at L5/S1 joint with University of Michigan 3D Static Strength Prediction Program [Chaffin et al.,1987; Chaffin andErig,1991].

[e]NIOSH Lifting Index, object weight divided by Recommended Weight Limit [Waters et al., 1993]. [f]Probability of high-risk group membership measured with Ohio State University Lumbar Motion Monitor [Marras et al., 1993].

Research such as ours can identify modifiable risk factors and inform interventions to decrease work-related low back stress and ultimately LBP. Modifiable risk factors for fishermen in this study included static, awkward postures for sorting tasks, manual materials handling tasks during loading and unloading activities, and operating pullers and net reels. A participatory ergonomic intervention study is currently being conducted with commercial crab pot fishermen to develop inexpensive tools and equipment to decrease low back stress. Our research indicates that fishermen are willing participants in studies and involving commercial fishermen early on in a participatory capacity is vital to the success of intervention research. This will likely increase adoption of beneficial changes and address recognized worker needs that are cost efficient. This study demonstrated that a multi-disciplinary approach that combined ethnographic techniques and detailed ergonomic assessments with epidemiologic outcome and exposure data can lead to interventions that will hopefully improve the work environment and productivity for commercial fishermen.

Limitations

These findings may reflect a healthy worker effect with those who fished longest having the lowest occurrence of severe LBP. The fishing task results in our study provide some evidence of this self-selection of tasks or addition of crew, because some tasks with higher biomechanical stress values (i.e., loading bait or supplies, pulling in or emptying gear) were not associated with the occurrence of severe LBP. The results obtained when stratifying by history of severe LBP support the hire of crew members to perform the more stressful tasks. However, we could not determine in our data whether fishermen hired crew or selected out of tasks because of previous LBP. Our findings for years of experience are consistent with healthy worker effect reported in other studies of commercial fishermen [Torner et al., 1988a; Lipscomb et al., 2004].

The population recruited for the cohort study included licensed commercial fishermen. However, not all fishermen need a license and most mates are not licensed. Therefore, a self-defined "mate" in the cohort may not be the same as the "mates" for whom we measured biomechanical stress with PATH and CABS [Kucera et al., 2008]. They were largely unlicensed, young workers employed to help the captains. This should be kept in mind when trying to generalize results.

We do not have complete information on everyone in the cohort; therefore, our analysis was limited to the 105 who answered the supplemental questionnaire and supplied information on fishing work history. Our task and ergonomic analyses were restricted to the 89 crab pot and gill net fishermen reducing precision further. Small sample size limited our ability to look at combined effects with a multivariate model in our analyses, illustrated by the wide confidence intervals. Supplemental questionnaire participants reported a higher occurrence of severe LBP compared to the whole cohort, which provides some evidence for possible selection bias.

Commercial fishermen are a dispersed workforce and difficult to reach with traditional research methods. Individual exposure assessment was not possible and beyond the scope of this study. Therefore, we used previous PATH and CABS exposure measures from a group of fishermen (n ¼ 25) [Kucera et al., 2008] to estimate individual ergonomic stress in crab pot and gill net fishermen who answered the supplemental questionnaire. Group assignment of exposure can lead to misclassification of exposure and potential bias in our estimates.

There were risk factors known to be associated with low back stress and low back pain that we were unable to examine in our study. We did not measure biomechanical stress of other fishing types or non-fishing-related work but examined variables to explore these effects.

Previous studies have reported boat motion increase musculoskeletal strain for fishermen [Petersen et al., 1989: Torner et al., 1994]. We observed this qualitatively; however, magnitude of motion is affected by weather and self-correction, and we were unable to account for this variable in our analyses.

Strengths

This study had many strengths. We were able to estimate in a unique population of small-scale, independent commercial fishermen the association between the occurrence of severe LBP and crab pot and gill net fishing tasks and biomechanical low back stress. This is the first study to use ergonomic commercial fishing work exposure measures accounting for variation between crew sizes and job types in a predictive model.

A prospective cohort design was employed to assess LBP and fishing types performed over a 2-year follow-up period. Previous studies of LBP in commercial fishing utilized cross-sectional and retrospective designs [Torner et al., 1988a; Norrish and Cryer, 1990; Jensen et al., 2005]. Use of a prospective cohort design generally decreases the chance of survivor bias.

Detailed interviews with commercial fishermen from the ethnographic study furthered our understanding of the fishing process and informed our ergonomic analysis. Together with the detailed epidemiological data from telephone interviews and clinic visits. this study had a broad and rich context from which to study low back pain associated with commercial fishing work. Most of commercial fishing research has been conducted with large-scale fishing operations, but relatively little is known about small-scale fishing operations such as those studied here.

CONCLUSIONS

Our results demonstrate that neither fishing task frequency nor ergonomic measure alone consistently predict LBP. History of LBP, addition of crew members, and likely self-selection out of tasks were important contributors to low back stress and outcomes. We observed variability in the way fishing work was conducted but were limited in our ability to account for reported differences in our analysis. Possible explanations for this discrepancy are revealed by the fishermen themselves. Fishermen who said they changed the way they fished due to LBP did so by doing less stressful work (e.g., lifting less or work slower), being more careful, using or bending legs when lifting, and lifting with help. Several reported using a puller or net reel, a back brace. antifatigue mat. or a longer pole while some adjusted the sorting table height or changed the way they shook the crab pot. One fisherman reported re-outfitting the boat to fish off the port (left) side. We can only speculate as to how these modifications might mediate or prevent severe LBP. Future research should focus on both stressful tasks identified with ergonomic assessments and tasks associated with LBP (e.g., sorting catch, loading and unloading, maintenance work). It is important to know how and why fishermen might adjust their exposures to low back stresses.

REFERENCES

Buchholz B, Paquet V, Punnett L, Lee D, Moir S. 1996. PATH: A work sampling-based approach to ergonomic job analysis for construction and other non-repetitive work. Appl Ergon 27:177–187.

Burdorf A, Sorock G. 1997. Positive and negative evidence of risk factors for back disorders. Scand J Work Environ Health 23:243–256.

Chaffin D, Erig M. 1991. Three-dimensional biomechanical static strength prediction model sensitivity to postural and anthropometric inaccuracies. IIE Trans 23:215–226.

Chaffin D, Freivalds A, Evans S. 1987. On the validity of an isometric biomechanical model of worker strengths. IIE Trans 19:280–288.

Fulmer S, Buchholz B. 2002. Ergonomic exposure case studies in Massachusetts fishing vessels. Am J Ind Med 42:10–18.

Jensen O, Stage S, Noer P. 2005. Classification and coding of commercial fishing injuries by work processes: An experience in the Danish fresh market fishing industry. Am J Ind Med 47:528–537.

Kucera K, Mirka G, Loomis D, Marshall S, Lipscomb H, Daniels J. 2008. Evaluating ergonomic stresses in North Carolina commercial crab pot and gillnet fishermen. J Occup Environ Hyg 5:182–196.

Kuorinka I, Jonsson B, Kilbom A, Vinterberg H, Biering-Sorensen F, Andersson G, Jorgensen K. 1987. Standardized Nordic questionnaires for the analysis of musculoskeletal symptoms. Appl Ergon 18:233–237.

Lavender S, Oleske D, Nicholson L, Andersson G, Hahn J. 1999. Comparison of five methods used to determine low back disorder risk in a manufacturing environment. Spine 24:1441–1448.

Liang K, Zeger S. 1986. Longitudinal data analysis using generalized linear models. Biometrika 73:13–22.

Lipscomb H, Loomis D, MacDonald M, Kucera K, Marshall S, Leiming L. 2004. Musculoskeletal symptoms among commercial fishers in North Carolina. Appl Ergon 35:417–426.

Marras W, Lavender S, Leurgans S, Rajulu S, Allread W, Fathallah F, Ferguson S. 1993. Role of dynamic three-dimensional trunk motion in occupationally-related low back disorders: The effect so workplace factors, trunk position, and trunk motion characteristics on risk of injury. Spine 18:617–628.

Marras W, Lavender S, Leurgans S, Fathallah F, Ferguson S, Allread W, Rajulu S. 1995. Biomechanical risk factors for occupationally related low back disorders. Ergonomics 38:377–410.

Marshall S, Kucera K, Loomis D, McDonald M, Lipscomb H. 2004. Work-related injuries in small scale commercial fishing. Injury Prev 10:217–221.

McDonald M, Kucera K. 2007. Understanding non-industrialized workers' approaches to safety: How do commercial fishermen "Stay safe"? J Saf Res 38:289–297.

McDonald M, Loomis D, Kucera K, Lipscomb H. 2004. Use of qualitative methods to map job tasks and exposures to occupational hazards for commercial fishermen. Am J Ind Med 46:23–31.

Mirka G, Kelaher D, Nay D, Lawrence B. 2000. Continuous Assessment of Back Stress (CABS): A new method to quantify low-back stress in jobs with variable biomechanical demands. Hum Factors 42:209–225.

Mirka G, Shin G, Kucera K, Loomis D. 2005. Use of CABS methodology to assess biomechanical stress in commercial crab fishermen. Appl Ergon 36:61–70.

Moe C, Turf E, Oldach D, Bell P, Hutton S, Savitz D, Koltai D, Turf M, Ingsrisawang L, Hart R, Ball JD, Stutts M, McCarter R, Wilson L, Haselow D, Grattan L, Morris JG, Weber DJ. 2001. Cohort studies of health effects among people exposed to estuarine waters: North Carolina, Virginia, and Maryland. Environ Health Perspect 109:781– 786.

Norrish A, Cryer P. 1990. Work related injury in New Zealand commercial fishermen. Br J Ind Med 47:726–732.

Petersen I, Torner M, Hansson T, Zetterberg C, Kadefors R. 1989. The effect of ship motions on the musculo-skeletal system of fishermen. Bull Inst Marit Trop Med Gdynia 40:211–216.

Poole C. 2001. Low P-values or narrow confidence intervals: Which are more durable? Epidemiology 12:291–294.

Punnett L, Fine L, Keyserling W, Herrin G, Chaffin D. 1991. Back disorders and nonneutral trunk postures of automobile assembly workers. Scand J Work Environ Health 17:337–346.

Riihimaki H. 1991. Low-back pain, its origin and risk indicators. Scand J Work Environ Health 17:81–90.

Rothman K, Greenland S. 1988. Modern epidemiology. 2nd edition. Philadelphia, PA: Lippincott-Raven Publishers.

Torner M. Blide G, Eriksson H, Kadefors R, Karlsson R, Petersen I. 1988a. Musculo-skeletal symptoms as related to working conditions among Swedish professional fishermen. Appl Ergon 19:191–201.

Torner M, Blide G, Eriksson H, Kadefors R, Karlsson R, Petersen I. 1988b. Workload and ergonomics measures in Swedish professional fishing. Appl Ergon 19:202–212.

Torner M, Almstrom C, Karlsson R, Kadefors R. 1994. Working on a moving surface—A biomechanical analysis of musculo-skeletal load due to ship motions in combination with work. Ergonomics 37:345–362.

Waters T, Putz-Anderson V, Garg A, Fine L. 1993. Revised NIOSH equation for the design and evaluation of manual lifting tasks. Ergonomics 36:749–776.

Waters T, Baron S, Piacitelli L, Anderson V, Skov T, Haring-Sweeney M, Wall D, Fine L. 1999. Evaluation of the revised NIOSH lifting equation: A cross-sectional epidemiologic study. Spine 24:386–395.

Zeger S, Liang K. 1986. Longitudinal data analysis for discrete and continuous outcomes. Biometrics 42:121–130.

SPECIFIC AIM #2: DEVELOP PROFILE OF THE BIOMECHANICAL DEMANDS

AIM #2; PAPER #1

TITLE: Evaluating Ergonomic Stresses in North Carolina Commercial Crab Pot and Gill Net Fishermen

ABSTRACT

There are challenges in evaluating physical demands of commercial fishing, including identifying sources of exposure variability. Low back biomechanical stresses associated with crab pot and gill net fishing were estimated; the variability was partitioned between and within fishing type, crew size, job title, and worker to improve understanding of risk factors for low back injury. The authors observed 162 person-hours of work among 25 North Carolina commercial fishermen on 16 crews. Postures and forces during fishing tasks were measured through direct and indirect observation using two methods to determine the percentage of time fishermen were exposed to high levels of low back stress. A multilevel linear model estimated exposure variability for the dependent variables by four nesting variables: fishing type, crew size, job title, and worker. Fishermen set and pulled crab pots or gill nets for 80% of the workday. Twenty-five percent of that time was spent handling gear. For both fishing types, handling heavy loads produced high peak compression values (3586 N to 5315 N) and high NIOSH lifting index values (3.3 to 5.4), but these tasks represent a small percentage of the overall work time (0 to 14%). The majority of exposure variation in non-neutral trunk posture and/or force >9kg, handling materials, NIOSH Lifting Index >1, and Lumbar Motion Monitor probability of high-risk group membership >70% was accounted for by fishing type (range 60 to 91%). Crew size was not an important source of variability for these six variables when fishing type and job title were accounted for in the model; but in the model restricted to crab pot fishing, crew size accounted for 51 to 88% of the variability in low back stress. For both models, job title comprised the majority of exposure variability for NIOSH Lifting Index >3.0 (46 and 65%) and worker comprised the majority of variability for spine compression >3400 N (54 and 65%). The magnitude and duration of musculoskeletal loads experienced by fishermen vary by the type of fishing and the tasks performed by the worker. Understanding this variability may help researchers target ergonomic interventions for this work population.

INTRODUCTION

Commercial fishing is physically demanding work characterized not only by high mortality[1-6] but also acute traumatic injury[4,7-12] and musculoskeletal pain.[11,13-15] Among workers in this dangerous occupation, injury rates differ by type of fishing, work process, and body part. Fatal injury rates ranged from 407 per 100,000 per year for shellfish to <50 per 100,000 per year for groundfish.[5] The percentage of nonfatal injuries differ by work process ranging from 24% for hauling the gear to 1% for working in the engine room.[16] Differences in the location of the musculoskeletal symptoms have also been noted among fishermen. Prevalence of musculoskeletal symptoms in Swedish fishermen ranged from 11% for foot and ankle to 51% in the low back, and the prevalence varied as a function of type of fishing method, job title, and by experience level.[13]

A number of work-related factors have been found to contribute to the risk of musculoskeletal strain in commercial fishing, including work pace, boat motion, use of nonroutine gear, catch handling techniques, and job rotation.[17,18] These work-related factors can vary by fishing type and position on the crew. Case studies in three types of Massachusetts fishing operations (lobstering, otter trawling, and gill netting) described differences in ergonomic exposures by fishing type and, within a fishing type, between captains and crew members.[18] These studies described significant ergonomic hazards but did not formally examine exposure variability between and within groups and individuals, which is important for accurately assessing exposure.[19] Occupational research indicates that the percentage of time in non-neutral trunk postures and handling physical loads varies between and within occupational groups and workers, and the contribution of between and within variance is different.[20–24]

Some of the authors' previous work established the magnitude of the problem of musculoskeletal disorders in small-scale North Carolina commercial fishermen.[15,25,26] These results showed that 17% of the commercial fisherman in the cohort experienced low back symptoms that interfered with work in the previous 12 months.[15] In a follow-up study, interviews with commercial fishermen were used to develop a seasonal round[25] and a job exposure matrix[15] that identified strenuous work tasks and hazards and suggested potential sources of exposure variability. These two studies informed pilot ergonomic work with two-man and three-man crab pot fishing crews. The results of this pilot work showed that over half of the workday was spent without weight in upright tasks, and exposure to low back stress differed by job title and crew size.[26]

From an injury prevention perspective, it is important to determine which work activities produce high levels of low back stress and how these stresses differ across types of fishing, crew size, and job characteristics. The focus of the current study was to evaluate the factors affecting low back stress in two groups of commercial fishermen from the inland rivers and sounds of eastern North Carolina: crab pot fishermen and gill net fishermen. The authors employed two methods to evaluate low back stress and estimated the variability between and within type of fishing, size of crew, and job title.

Background on North Carolina Fishing

Crab pots and gill nets are the most commonly used fishing gear in North Carolina, representing 43.8% and 21.8% of 243,993 commercial fishing trips recorded in 2000.[10,27] The process of fishing for crabs with pots and finfish with gill nets has been described previously[25,26] and is briefly summarized here. Crab pots, made from sheets of plastic-coated wire formed around a metal bar box frame 0.6 × 0.6 × 0.5 m, weigh 6kg when empty, have three openings, and are set individually, marked by buoys, in rows along the sound or river bottom. To pull the pots up, fishermen catch the rope around the buoy with a metal hook and wind the rope around a hydraulic puller or, alternatively, pull the pot in by hand. They lift the pot in, dump out old bait, unhook the pot opening, and shake out crabs onto a work surface or box. Once empty, the pot is hooked closed, rebaited with two to three fish, and reset.

Gill nets are composed of a monofilament mesh that is strung between two lines. The top line has cork floats attached so that the net sits vertically in the water column. A buoy and an anchor mark each end of the net. Fishermen use a metal hook to catch the buoy and feed the line into a hydraulic puller. After the anchor is removed, the line is wound around a large metal rotating drum that pulls the net in and down a wooden chute or table. With no puller or net reel, fishermen alternatively pull lines and nets in by hand. As the net is pulled along, fishermen pick out and toss fish into boxes. Culling (sorting catch to remove illegal-sized finfish or crabs) is required by law and performed on the boat.

METHODS

Study Population

Participants for this study were recruited through telephone interviews with two groups of previously studied commercial fishermen from eastern North Carolina.[7,15,25,26,28] The first group included a cohort of 217 commercial fishermen aged 18 to 65 originally recruited to study possible health effects of exposure to an estuarine organism.[28] The second group consisted of 33 commercial fishermen aged 18 to 80 who had participated in a previous ethnographic study about their work as commercial fishermen.[25] During the telephone interview, participants were asked if they would allow a researcher to observe, photograph, and videotape them working.

A total of 119 fishermen were interviewed by phone and asked to participate in this study; 45% (54/119) were willing to be observed while fishing. Due to time and financial constraints, the study population was a purposive sample of 25 crab pot and gill net fishermen. Participants observed were predominantly male (90%) and white, non-Hispanic (93%) (Note: The term "fisherman" is used because that is how the participants, men and women, referred to themselves and to others.) The authors observed 162 person-hours of fishing work by 25 fishermen (20 crab pot; 5 gill net) on 16 crews (12 crab pot; 4 gill net), of which 108 person-hours were captured on video (Table 1). The University of North Carolina at Chapel Hill School of Public Health Institutional Review Board approved all study procedures. Full details of recruitment and study protocols for the cohort and ethnography group have been previously reported.[7,15,25,26,28]

Overview of Ergonomic Methods

Commercial fishing jobs have highly variable tasks and lifting demands and therefore require specialized assessment techniques to be able to accurately reflect this variability. Two ergonomic tools were used to assess the range of ergonomic exposures for commercial fishermen. These tools described below were designed for the construction industry (an industry that shares this characteristic of variable biomechanical demands) and have been used to evaluate commercial fishing.[18,26]

The Posture, Activity, Tools and Handling (PATH) method[29] is a work sampling approach that measures the frequency of tasks, postures, material handling activities, and tool use. By linking work tasks and activities to posture codes from the Ovako Work Posture Analyzing System,[30] PATH yields the percentage of work time that workers are exposed to non-neutral or awkward postures and handling heavy loads.
Because PATH samples postures and activities throughout the entire workday, quantification of the variability of postures and loads is possible.

TABLE I. Number of Crew Types and Workers, PATH and CABS Observations

Type of Fishing	Crew Size	Job	Number Crews (%)	Number of Workers (%)	Days	PATH Number of Observations[A]	CABS Number of Workers Included in Histograms
Crab pot							
	1 man	Captain	4 (33%)	4 (18%)	1	583	2
	2 man[B]		6 (50%)			1448	
		Captain		6 (27%)	1		2
		Mate		6 (27%)	1		2
	3-man		2 (17%)			559	
		Captain[C]		1 (5%)	2		2
		Mate[C]		1 (5%)	2		2
		3rd man		2 (9%)	1		2
	Total		12	22		2590	12
Gill net							
	1 man	Captain	3 (75%)	3 (60%)	1	125	1
	2 man[B]		1 (25%)			321	
		Captain		1 (20%)	1		1
		Mate		1 (20%)	1		1
	Total		4	5		446	3
Total			16	27*B*		3036	15

[A] PATH observations measured from videotape with researcher in the lab.
[B] One 2-man crew measured crab pot and gill net fishing; n = 25 individual fishermen were observed.
[C] Captain and mate on crab pot 3-man crew observed on 2 days.

The second tool, Continuous Assessment of Back Stress methodology (CABS),[31] uses three well-established ergonomic assessment methods to evaluate biomechanical stress of occupational activities: the Revised National Institute of Occupational Safety and Health Lifting Equation (NIOSHLE),[32] the Ohio State University Lumbar Motion Monitor model (LMM),[33] and the University of Michigan Three-Dimensional Static Strength Prediction Program (3DSSPP).[34,35] The measures from these assessment tools (lifting index from the NIOSH equation, probability of high-risk group membership from the LMM model, and the compression from the 3DSSPP), combined with time-coded sub-tasks, produce histograms that illustrate the proportion of the workday workers experience varying levels of low back stress.

Considered separately, the NIOSHLE and LMM have been described as better assessment tools for repetitive jobs with lower peak loads consistent with long-term cumulative trauma risks, whereas the 3DSSPP best addresses acute trauma risks from awkward postures and one-time heavy lifts.[31] Each tool addresses an important factor in the risk of low back disorder and injury. Combining these three techniques as a hybrid allows researchers to better represent work with variable tasks. While it is recognized that a number of the tasks performed in commercial fishing violate some of the assumptions of these underlying models (e.g., one-handed lifts violate the two-handed lift assumption of the NIOSH lifting equation), these models can provide an assessment of the relative stress across fishing type, crew size, and job title.

Both methods were used in this study because PATH and CABS have different ways of measuring ergonomic stress. CABS is a rigorous biomechanics-based methodology that provides quantitative measures of spine stress. PATH is an observational assessment technique designed to be used in the field and describes frequency of exposure to postures and forces but does not quantify the magnitude of these forces directly.

Data Collection

From 2001 to 2004, researchers accompanied crab pot and gill net commercial fishing crews (1 man, 2 man, and 3 man [crab pot only]) and videotaped all aspects of fishing work during a full day. Most crews were observed only once, but one crew was observed crab pot fishing on two days, and one crew was observed crab pot fishing one day and gill net fishing one day.

PATH templates containing job titles, tasks, and activities for crab pot and gill net fishing were created prior to the trips based on the videos and interviews gathered previously from the ethnographic group fishermen,[25] direct observations, and previous fishing industry studies.[13,17,18] The following PATH variables were captured: job title; trunk, leg, and arm postures; fishing task; activity performed; tools used; material handling; force or weight handled; coupling; and position of the material relative to the body. PATH observations were recorded by one researcher every 90 sec for each worker whenever they were visible on the videotape using a hand-held computer (Inspect-Write Inspection Management software 7.0, PenFact, Inc., Boston, Mass.). During 108 person-hours of video footage of 25 fishermen, the authors collected 3036 PATH observations.

For CABS, fishing activities were broken down into a series of functional subtasks (e.g., hook buoy, shake pot, load bait). All pre/post fishing activities (loading and unloading, etc.) and three or more samples of the fishing work cycle were coded with a computer-based video coding system for the CABS analysis (OCS Tools, Triangle Research Collaborative, Inc., Research Triangle Park, N.C.). The OCS coding system quantified the time and frequency workers spent performing CABS subtasks during the sampling period. For example, in order to calculate the amount of time per subtask, time was noted at the end of each subtask and then summed over the frequency that the subtask was performed to result in an overall time value.

Three-Dimensional Modeling

After viewing and coding the videotapes, three-dimensional stick figure models were constructed for each CABS subtask using the 3DSSPP computer program (3DSSPP 4.0, University of Michigan, Ann Arbor, Mich.). A worker's posture was determined from the videotaped image, and the computer stick figure was adjusted to match the video image. The model for static subtasks represented the static posture that the worker held (e.g., trunk flexed for sorting catch), while the model for dynamic subtasks represented the peak stress position or position with the greatest moment about the lumbar spine (e.g., trunk flexed for grab buoy). Inputting major joint angles and direction and magnitude of forces provided X, Y, and Z moments about the spine as well as compression values at the L5/S1 joint in Newtons (N).

Models were constructed assuming a 50% anthropometry so they could be applied to all the fishermen in the study. Materials were weighed and units of mass were applied to all models:

36 kg totes or box, 18 kg basket, 9 kg crab pot, and 18 kg anchor. Estimated forces included pulling in the net (69 N) and hooking the buoy (49 N).

Trunk Kinematics Data Collection

To capture the trunk kinematics variables necessary for the LMM risk assessment model, the various fishing subtasks were simulated in the laboratory by two graduate students (noncommercial fishermen). Ideally, these data would have been collected on the water, but concerns with regard to the sensitivity of the LMM equipment prohibited this approach. After viewing video footage of a fisherman performing a given subtask, the volunteer simulated the task multiple times, attempting to replicate the varied techniques the worker employed to complete the task. Three-dimensional position, velocity, and acceleration of the lumbar spine were recorded over the multiple trials (up to nine) per task and input into the LMM risk assessment model. Maximum moments were calculated from moment arm length and object weight. Moment arm length was measured as the horizontal distance between the load and the spine for each modeled task from the 3DSSPP and NIOSHLE. The final variable for this model, lift rate (expressed in lifts/hour), was calculated from the videotapes for each crew member for loading, unloading, and during three samples of fishing work cycles to account for hourly variations in work cycle.

The probability of high-risk group membership was derived from: lift rate (lifts/hour), average twisting velocity (degrees/second), maximum moment (Newton-meters), maximum sagittal flexion (degrees), and maximum lateral velocity (degrees/second). The probability of high-risk group membership was calculated for each trial and averaged across trials. This average represents the overall assessment for that subtask. The high-risk, low back disorder group is defined operationally as a job with greater than 12 reported low back disorder incidents per 200,000 hours of exposure.[33,36]

The 3-D models and laboratory simulations were used to obtain NIOSHLE measures to calculate a lifting index (LI): object weight divided by the recommended weight limit (RWL) defined as the appropriate weight that can safely be lifted by most of the working population. RWL is calculated from: horizontal distance between object and body, initial lift height, vertical displacement of the load, frequency of lifts, lift asymmetry, and quality of the hand-container coupling. The lifting index estimates the relative physical demand of a specific task on the lumbar spine. For example, a lifting index of 1.0 indicates the physical demand is at the NIOSH recommended weight for that lift, while a lifting index of 2.0 would indicate that the worker is lifting twice the NIOSH recommended weight for that lift.

Data Analysis

PATH observation frequency and distributions were stratified according to fishing type (crab pot or gill net), size of crew (1 man, 2 man, or 3 man [crab only]), and job title (captain, mate, or 3rd man [crab only]). CABS compression, lifting index, and the probability of high-risk group membership measures were merged by subtask with the time and frequency the fisherman performed a particular subtask over the day to produce time-weighted histograms. For example, a fisherman observed pulling in a crab pot 20% of total time caught on video was assigned the corresponding pulling in the pot CABS measure for 20% of the day. Low back compression histograms represent the percentage of time in a workday that each worker or crew is exposed to that range of spine compression.

Lifting index and probability of high-risk group membership histograms represent the relative frequency of lifts at the given index or probability. Due to the time-intensive nature of

CABS coding, histograms were not generated for all 108 hours with all 27 fishermen; 63 person-hours of video were sampled from 15 fishermen (12 crab pot. 3 gill net) representing eight crews (6 crab pot, 2 gill net). Crews were selected purposefully to represent the different work intensity and pace of the crews.

For this study, the authors constructed one 3DSSPP model, one LMM simulation, and one lifting index per CABS subtask and generalized them to apply to the fishermen. Therefore, the individual component for CABS measures were encompassed by the subtask time and frequency values assigned to each CABS measure. Alternate models were constructed for subtasks that showed high variability between workers and boats. For example, Model A for "hook buoy" has the worker hooking the buoy with one hand. Model B for "hook buoy" has the worker hooking the buoy with two hands. CABS values for Models A and B were compared, and 50% of sampled time was assigned to each subtask model for time-weighted histograms. The authors also quantified and compared the effects of using a metal hook and pot puller vs. performing those subtasks by hand.

PATH and CABS exposure variables were created using cut points established from previous occupational studies. Non-neutral trunk postures,[37,38] lifting 44.5 N (4.5 kg) at least once per minute,[37] and material handling tasks[38,39] have been identified as risk factors for low back pain. Non-neutral trunk postures were defined as any one of the following: trunk flexion >20 degrees; lateral bend and twist >20 degrees; or lateral bend, twist. and flex >20 degrees. PATH templates categorized forces at 9 kg and 18 kg; therefore, exposure to forces was defined as fishermen handling loads >9 kg. The combination of non-neutral trunk posture with force >9kgwas examined to capture the multidimensionality of these two exposures.

Compression values greater than 3400 N has been associated with an increased risk for low back pain among workers.[40] Lifting indices greater than 1.0 have been associated with low back pain, while indices over 3.0 are reported as a potential problem for most workers.[32,40,41] Two variables were created for the lifting index and they were not mutually exclusive: percentage of time LI >1.0 and percentage of time LI >3.0. Probability of high-risk group membership of 35% or more has been identified as a problem for industrial workers.[36] Because the majority of fishing tasks were estimated to have greater than 35% probability of high risk group membership, the authors raised the criteria for the probability to >70% for this analysis.

Modeling Variability

Dependent variables for analysis of variance were defined as the percentage of time each worker exceeded the established cut points described above (e.g., the percent of time in non-neutral trunk postures). Variability between and within type of fishing, crew size, job title, and worker was quantified with a decomposition of variance using multi-level (mixed) linear models (SAS Version 8.2, SAS Institute Inc., Cary, N.C.). In the models, the intercept was suppressed and random effects were included for four nesting (class) variables: worker ($i = 21$), job title ($j = 3$), crew size ($k = 3$), and type of fishing ($m = 2$). Models started with the highest order class variable (type of fishing), and lower order class variables were added one at a time to determine their contribution to the overall variance. For type of fishing, the fully adjusted model estimated exposure variability between type of fishing, between crew sizes within type of fishing, and between job titles within crew size within type of fishing. The fully adjusted model was specified by the following equation:

$$Y_{j(km)} = a_m + w_{k(m)} + s_{j(km)} + r_{jkm} \quad (1)$$

where $Y_{j(km)}$ was the dependent variable (e.g., mean percentage of time in non-neutral trunk posture) for jth job title on a crew of size k performing the mth type of fishing; a_m was the effect of the mth type of fishing performed by the crew (gill net or crab pot) and was normally distributed with variance σ_F^2; $w_{k(m)}$ was the effect of the size of the kth crew size performing the mth type of fishing and was normally distributed with variance σ_C^2; sj(km) was the effect of performing the jth job title on a crew of size k performing the mth type of fishing and was assumed to be normally distributed with variance σ_J^2. The variance not explained by job title, crew size, and type of fishing was r_{jkm} and assumed to be normally distributed with estimate of σ^2. This residual represents the variance between worker, within worker, and by day.

Nested models examined exposure variability in crab pot fishing between crew size (wk), between job title within crew size ($s_{j(k)}$), and between workers within job title within crew size ($t_{i(jk)}$). These models were not run for gill netting because a 3-man crew and repeated measures were not available. The variance not explained by worker or job title, and crew size was r_{ijm} and was assumed to be normally distributed with estimate of σ^2. This residual represents the variance within worker and between and within a day.

Previous studies have modeled the variability for percentage of time in trunk flexion and handling loads using a log-transformed variable.[21] The authors did not log transform dependent variables due to the difficulty in interpreting beta coefficients for a log-transformed variable as an adjusted mean. While extreme departures from normality can yield spurious results,[42] the distributions of the dependent variables in the current study data followed an approximately normal distribution, and log transformations did not improve the fit. Cell sizes ranged from 5 to 1 for these analyses.

RESULTS

Posture, Activity, Tools, and Handling

The most common tasks for either fishing type were pulling in and setting pots or nets (80%) followed by traveling to fishing grounds (6%), loading and unloading (4%), and sorting catch (3%), with the remaining time spent cleaning (2%), docking and casting off (1%), and other activities (4%). The most common activities performed while pulling or setting fishing gear were handling/operating pots or nets (25%); operating controls to the boat, puller, or net reel (17%); and handling/guiding lines (14%). The percentage of time spent pulling or setting fishing gear varied by fishing type. Crab pot fishermen spent more time operating controls (32% crab pot vs. 3% gill net), while gill net fishermen spent more time handling lines (21% gill net vs. 6% crab pot), handling gear (35% gill net vs. 18% crab pot), and picking nets (32%) (Figure 1).

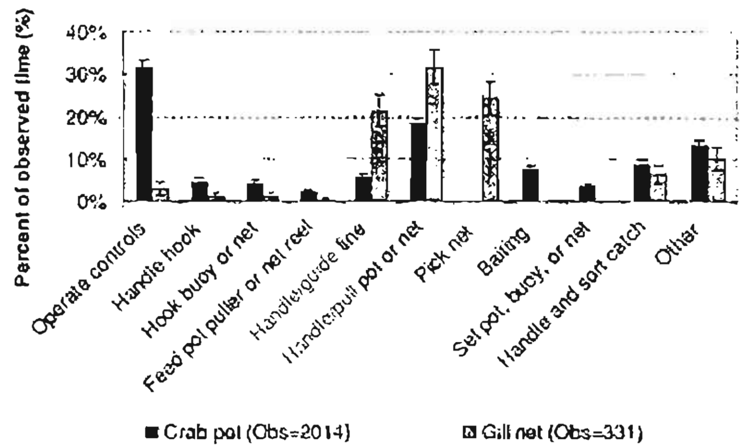


FIGURE 1. Percentage of time observed in commercial fishing activities for "pulling in gear" task by crab pot (n = 20) or gill net (n = 5) fishermen using Posture, Tools, Activities, and Handling (PATH) method.

Additional differences were observed by job title within and between fishing types (Figure 2a–b). Crab pot captains spent half the time operating controls vs. gill net captains who guided lines a majority of time. Gill net mates spent more of their day handling gear (80%) compared to crab pot mates (40%). The 3rd man for crab potting spent the majority of time sorting catch (41%).

Fishermen handled materials (e.g., baskets or boxes of catch) 28% of the time, with mates handling materials more (32%) than the captain (26%) and the 3rd man (23%). Fishermen exerted forces or handled loads during half the workday. Of that time, loads greater than 18 kg were observed infrequently (4%), while loads 9 to 18 kg were more common (19%), and loads less than 9 kg were observed most often (77%). During gill netting, crew members were exposed to loads 88% of time compared with less than half the time for crab potting (45%). Loads and forces varied by job title. In crab potting, the 3rd man was exposed to loads and forces more frequently (74%) than mates (52%) and captains (36%).

Overall non-neutral trunk postures were observed 24% of time. Moderate flexion (20 to 45 degrees) was observed most often (15%) compared with severe flexion (>45 degrees) (7%), and twisting and lateral flexion (1%). On average, trunk postures did not appear to vary between crab potting and gill netting nor when stratified by crew size. However, trunk postures differed by job title. The 3rd man spent 49% of the time in non-neutral trunk postures and 32% of time in severe flexion, whereas mates and captains spent 29% and 18% of the time in non-neutral trunk postures and only 9% and 3% in severe flexion.

Continuous Assessment of Back Stress

Analyses of the 108 person-hours of video footage of 25 fishermen identified 43 subtasks for crab pot and gill net fishing. Of these, 31 represented independent subtasks (sort catch, shake pot, drive, etc.). The remaining subtasks were weight dependent (i.e., lift up 18 kg basket vs. lift up 36 kg box) or required slightly different postures (i.e., pick net upright vs. pick net bent). Compression, lifting index, and probability of high-risk group membership mean and range are presented for selected CABS subtasks (Table II). One subtask, lift down tote (36 kg), was considered by all three methods as high risk (Table II).

For CABS histograms, 63 person-hours of video were sampled from 15 fishermen (12 crab pot, 3 gill net) representing eight crews (6 crab pot, 2 gill net). Although loading bait totes produced high compression values and lifting index values, these subtasks contributed little to the crew's overall work time (0 to 14%) compared with subtasks like driving the boat (29 to 81%), sorting catch (27 to 53%), and picking nets (48 to 53%), which contributed larger proportions of time to the workday and produced low levels of stress. The overall percentage of time at lower lifting indices indicated that light, hand-held loads represented most of the workday.

Compression and lifting index histograms illustrated differences in the distribution of biomechanical loading across fishing types. However, probability of high-risk group membership ranged from 40% to 100% for both fishing types. Half of the crab potting crew workday was spent in 0 to 680 N compression values, whereas 50% of the gill netting workday was at 680–1360 N of spine compression (Figure 3a– b). Compression, probability of high-risk group membership, and lifting index distributions varied by job title. Crab pot and gill net captains within different crew sizes experienced the largest variability. For crab potting, the 3-man crew crab pot captains and one 2-man crew captain spent the majority of time (78%, 91%, and 89%) from 0–680 N compression compared with both 1-man captains (44% and 51%) and the other 2-man captain (59%). Crab pot mates experienced the highest peak compression values (3586 N to 5315 N) and lifting index values (3.3 to 5.4) less than 10% of the workday during loading and unloading and overall spent greater than 40% of the workday at probability of high-risk group membership 80%. The 3rd man spent half the crab pot workday exposed to midrange compression values from 1360 to 2040 N. Likewise, gill net crew members' stresses differed between job titles (Figure 4a–c), the greatest experienced by the 2-man crew mate whose main task was pulling and picking fish from the net.

Alternate CABS Subtask Models

The two techniques for hooking the buoy (Model A vs. Model B) had similar compression and probability of high-risk group measures, but the lifting index was greater for Model A. Only the compression measure was different for the two techniques for feeding the pot puller (Model A vs. Model B, Table II). When retrieving the buoy from the water, the use of a metal hook (grab rope with hand vs. hook buoy) decreased the compression value and decreased lifting index only when the hook was used with two hands. The use of the pot puller (feed pot puller vs. pull pot rope by hand) decreased biomechanical stress in all three measures.

Variability of PATH and CABS Exposures by Type of Fishing, Crew Size, Job Title, and Worker

Decomposition of the variance in percentage of work time exposed to low back stress with nested models indicated variability between and within grouping variables. Type of fishing accounted for the majority of variability in all PATH variables (range 60.3 to 82.4%) and CABS lifting index >1.0 (65.2%) and probability of high-risk group membership >70% (90.5%) when crew size and job title (captain, mate, and 3rd man) were accounted for. Conversely, job title explained the majority of the variability for lifting index >3.0 (46.0%), and the residual (or worker) explained the majority of the variability for spine compression >3400 N (53.9%). Crew size contributed little to variability over all exposures for this model. Residual variation was highest for the percentage of work time in force >9kg (36.9%), non-neutral trunk plus force >9kg (32.9%), lifting index >3.0 (29.8%), and spine compression >3400 N (53.9%) and

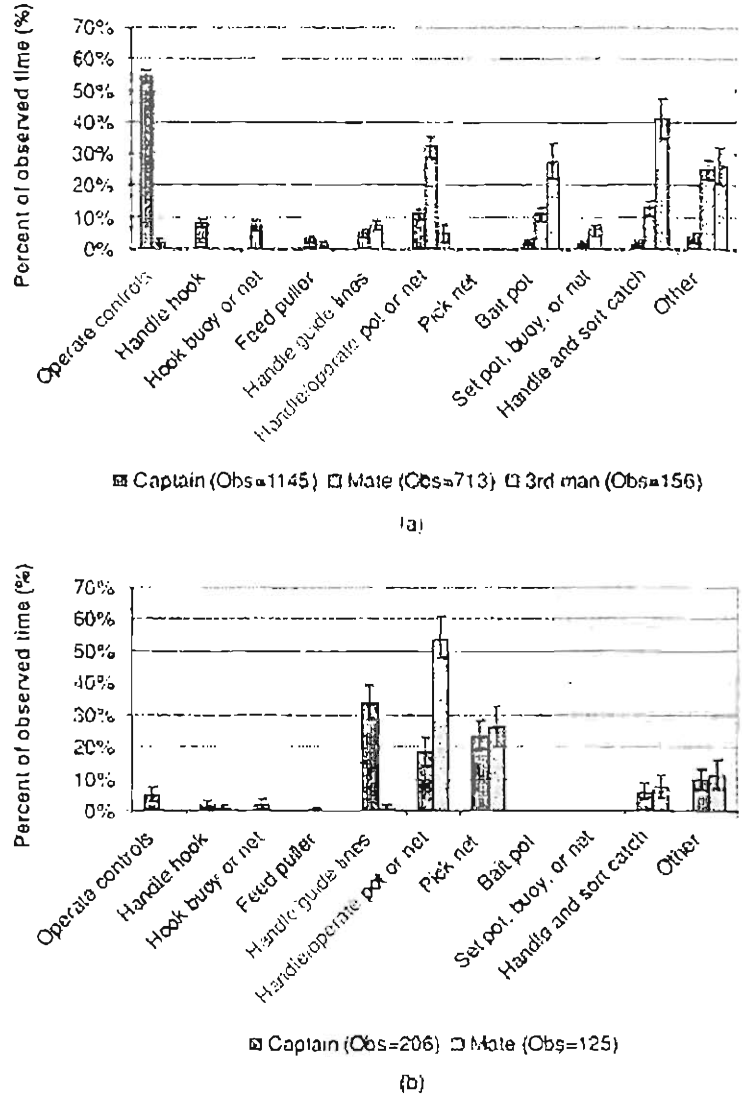


FIGURE 2. (a) Percentage of time observed in commercial fishing activities for task "pulling in gear" stratified by job title using Posture, Tools, Activities, and Handling (PATH) method—crab pot (10 captains, 6 mates, and 2 third men); (b) Percentage of time observed in commercial fishing activities for task "pulling in gear" stratified by job title using Posture, Tools, Activities, and Handling (PATH) method—Gill net (4 captains and 1 mate).

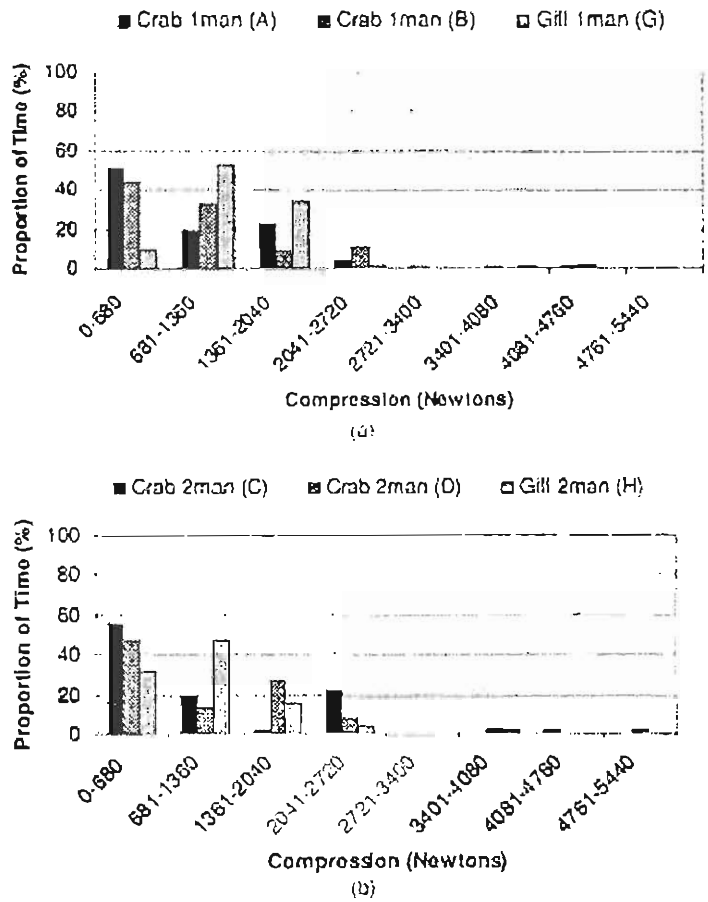


FIGURE 3. (a) Proportion of time for lumbar spine compression (Newtons) comparing 1-man crews between crab pot and gill net commercial fishing using Continuous Assessment of Back Stress (CABS) method. (b) Proportion of time for lumbar spine compression (Newtons) comparing 2-man crews between crab pot and gill net commercial fishing using Continuous Assessment of Back Stress (CABS) method.

included different workers in the same job title and different days within workers—a composite of within-job title and between and within-worker variation.

To quantify variation within job title and between workers, nested models were limited to crab pot fishing containing random effects for crew size, job title, and worker (Tables II and III). Crew size was responsible for a majority of the variability for all PATH variables and CABS lifting index >1.0 and probability of high-risk group membership >70%. Consistent with the previous model, job title contributed most to percentage of work time >3.0 lifting index, and worker contributed most to >3400 N spine compression. Worker (between individual) contributed little to total variability except for percentage of work time in non-neutral trunk plus force >9 kg, spine compression >3400 N, and lifting index >1.0. Residual variation remained high for lifting index >3.0 and represents within-worker and within-day variation.

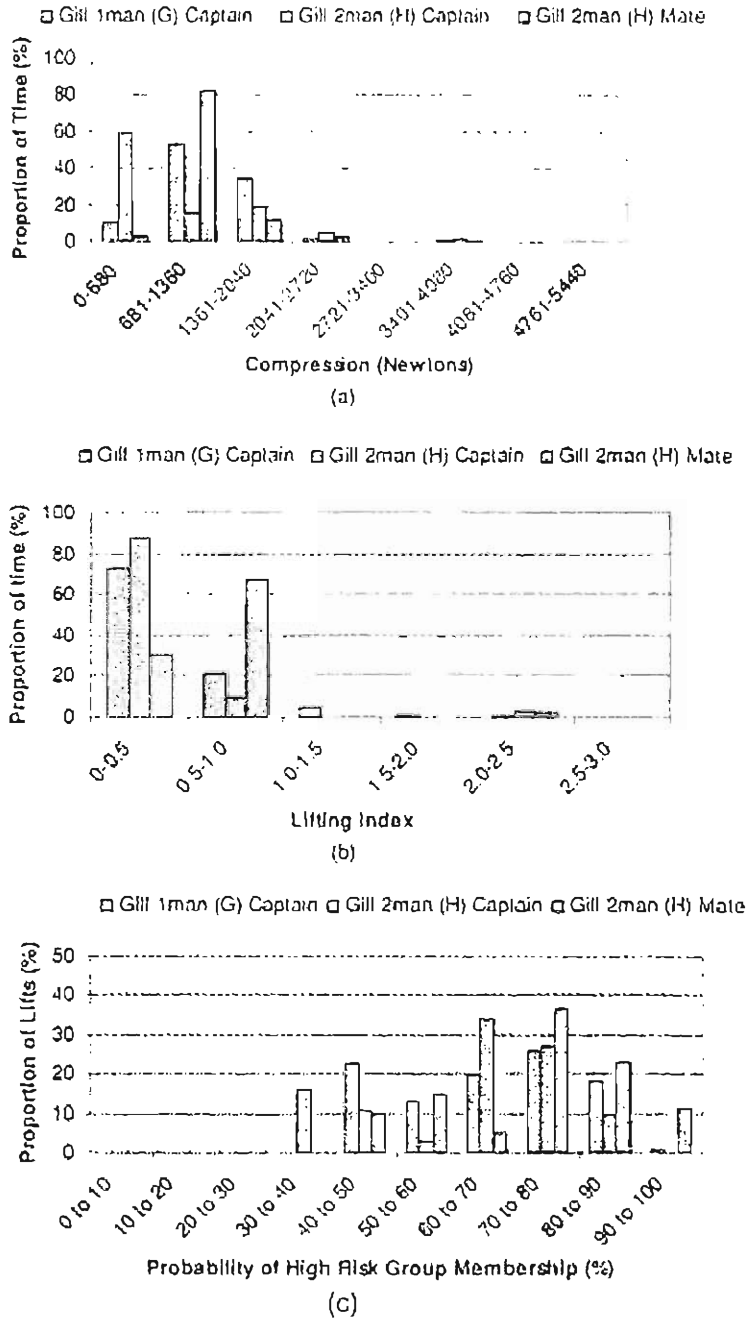


FIGURE 4. (a) Histogram of lumbar spine compression (Newtons) for gill net fishing captains and mates across different crew sizes using Continuous Assessment of Back Stress (CABS) method. (b) Histogram of NIOSH Lifting Index (LI) for gill net fishing captains and mates across different crew sizes using Continuous Assessment of Back Stress (CABS) method. (c) Histogram of probability of high-risk group membership for gill net fishing captains and mates across different crew sizes using Continuous Assessment of Back Stress (CABS) method.

TABLE II. Estimated Contribution of Different Sources of Variance to the Total Variability of Mean Percentage Time Exposed to Low Back Stress Measured with PATH

		Model #1	Model #2	Model #3
Non-neutral posture[A]	Parameter	%	%	%
	σ^2_C	85.2	75.3	75.3
	σ^2_J		19.7	19.7
	σ^2_W			0.0
	σ^2	14.8	5.0	5.0
	Total variance	779.11	816.18	816.16
Force >9kg (88.3 Newtons)[A]	Parameter			
	σ^2_C	75.7	59.0	64.3
	σ^2_J		29.5	21.5
	σ^2_W			12.8
	σ^2	24.3	11.5	1.4
	Total variance	181.84	184.67	177.17
Non-neutral trunk and force >9kg (88.3 Newtons)[A]	Parameter			
	σ^2_C	71.3	67.7	70.7
	σ^2_J		7.2	0.0
	σ^2_W			22.0
	σ^2	28.7	25.1	7.4
	Total variance	16.13	16.32	15.55
Handling materials[A,B]	Parameter			
	σ^2_C	82.6	72.9	77.0
	$\sigma2_J$		16.3	10.4
	σ^2_W			8.1
	σ^2	17.4	10.8	4.4
	Total variance	779.77	772.52	760.19

Note: Proportion of total variance: between crew size (σ_C^2), between job type within crew size (σ^2_J), and between worker within job within crew size (σ^2_W), and residual (σ^2); n = 20 fishermen.

[A] Percentage of observed workday.

[B] Lift, lower, carry, push/pull, slide, or hold.

DISCUSSION

This study evaluated low back stress in two types of fishing with methods developed for nonroutine work and estimated the variability between and within fishing type, crew size, job title, and worker. Fishing tasks identified as stressful for the low back by the PATH non-neutral postures and force >9kg cut points included pulling in the buoy, feeding the puller, handing pots and nets, and loading and unloading. These findings by PATH were supported by the CABS probability of high-risk group membership >70%. Spine compression and lifting index measures were high only for loading and unloading subtasks. The type of fishing explained the majority of the exposure variability when accounting for crew size and job title. Within crab pot fishing, crew size followed by job title were the major contributors to exposure variability. Exceptions included lifting index >3.0 and spine compression >3400 N for which job title and worker accounted for most of the exposure variability, respectively.

Low back stress exposures varied between fishing types in this study. Gill net fishermen were exposed to loads during almost 90% of the workday compared with about half of the workday for crab pot fishing. Gill net fishermen frequently handled the net as it was pulled in and picked clean of fish with or without the assistance of a net reel.

Conversely, crab pot fishermen handled pots a large proportion of the time but used the work table and boat for support when they opened, emptied, baited, and closed the pots. These results support previous findings from Massachusetts fishermen where differences in length of work cycle were responsible for the distribution of materials handling stress when lobster trap and gill net fishermen hauled in and emptied their gear.[18] Lobster fishing had shorter work cycles (12 min) compared with gill net fishing (60 min).[18]

The authors observed an upward shift in compression and lifting index histograms comparing crab pot with gill net fishing (Figure 3a–b). Further, decomposition of variance revealed that fishing type was responsible for a large proportion of the variability in exposure to low back stress that remained after adjustment by crew size and job title. Within a single type of fishing, crew size was important in determining a worker's exposure to stress. By sampling multiple crews and crew sizes in two types of fishing, the authors demonstrated that the independent effects of crew size were important within type of fishing (Tables II and III) but less so when examined between fishing types. Depending on how captains divided the work tasks in the current study, a 2man crew captain's low back stress distribution may resemble a 3-man crew captain. Division of labor (tasks) between crew members has been shown to be an important determinant of exposure to musculoskeletal stress.[17,18,26]

In a study of Massachusetts lobster fishing, differences in ergonomic exposures between crew members were also observed. Within lobster fishing, captains were exposed to awkward trunk and upper extremity postures in addition to high force and repetition when pulling in gear. Mates were exposed similarly when handling gear and, in addition, were exposed to repetition and awkward postures associated with gauging and banding catch.[18] Pilot work with eastern North Carolina crab pot fishermen found high stress activities were more evenly distributed between captain and mate in the 2-man crew, whereas with the 3-man crew the mate performed high force exertions and the 3rd man experienced static awkward postures.[26]

For both fishing types, residual variation was minimal (range 3% to 9%) except for percentage of time in force >9 kg, non-neutral posture combined with force >9 kg, lifting index >3.0, and spine compression >3400 N (range 30 to 54%) indicating that variation between and within worker was important for these variables. For crab pot, the variance that could not be accounted for in the analysis ranged from 0.8% to 22.7%. This residual includes different workers in the same job title, crew size, and type of fishing plus variability from day to day and within day.

TABLE III. Estimated Contribution of Different Sources of Variance to the Total Variability of Mean Percentage Time Exposed to Low Back Stress Measured with CABS

		Model #1	Model #2	Model #3
Compression >3400 Newtons[A]	Parameter			
	σ^2_C	33.9	30.1	32.4
	σ^2_J		22.7	0.0
	σ^2_W			64.6
	σ^2	66.1	47.3	3.1
	Total variance	71.1	72.6	66.2
Lifting Index >3.0[A]	Parameter			
	σ^2_C	25.4	12.8	12.8
	σ^2_J		64.5	64.5
	σ^2_W			0.0
	σ^2	74.6	22.7	22.7
	Total variance	24.34	24.98	24.98
Lifting Index >1.0[A]	Parameter			
	σ^2_C	61.5	47.3	50.6
	σ^2_J		39.6	29.2
	σ^2_W			19.4
	σ^2	38.5	13.1	0.8
	Total variance	829.85	809.82	797.60
Probability of high-risk group membership >70[A]	Parameter			
	σ^2_C	91.2	88.1	88.2
	σ^2_J		9.0	8.3
	σ^2_W			1.9
	σ^2	8.8	2.9	1.7
	Total variance	3186.18	3151.14	3130.11

Note: Proportion of total variance: between crew size (σ^2_C), between job type within crew size (σ^2_J), and between worker within job within crew size (σ^2_W), and residual (σ^2); n = 12 fishermen.
[A]Percentage of observed workday.

PATH and CABS

This project provided an interesting opportunity to compare and contrast two different risk assessment methods. Both methods indicated that a single task or activity may be associated with high levels of low back stress (e.g., lifting up box). In addition, when task stress was combined with frequency and duration, low-risk single tasks were identified as higher risk due to the increased time workers were exposed (e.g., sort catch).

As used in this study, PATH captured the between-and within-worker variability of low back stress better than CABS. Unlike CABS' use of peak stress positions for each task, PATH provided an inclusive assessment of posture for each activity by repeated sampling of that activity over the workday. CABS 3DSSPP models and LMM simulations were generalized so they could be assigned to any fisherman, whereas PATH measures are sampled for each individual.

Each method approaches low back stress from a different perspective. PATH's strength lies in its ability to characterize jobs with variable tasks and postures providing aggregated, posture-based exposure measures useful for epidemiologic analyses. However, the increased generalizability of PATH results is gained at the loss of detailed biomechanical exposure measures that are essential to determining task risk. CABS, on the other hand, does provide a quantification of low back stress using three different biomechanical assessment tools that are well established in occupational ergonomics.

Previous studies comparing ergonomic assessment methods identified trade-offs. Detailed and precise measures such as those from CABS require technological expertise and equipment at substantial time and cost, while simple, efficient, low-cost, and generalizable methods like PATH can be applied to a wide variety of work situations.[43,44] Both have their value and place when assessing musculoskeletal stress. The authors found that employing both, as was done here, provided a more comprehensive picture of work stresses but at considerable time and effort.

Limitations

The authors focused ergonomic assessments on crab potting and gill netting, two common fishing types in North Carolina. Lacking ergonomic assessments that describe other types of fishing, these results cannot be generalized beyond crab pot and gill netting. Due to the nature of commercial fishing work, the difficulties in reaching these workers at home, and scheduling trips, the authors were unable to observe a random, statistically representative sample of fishermen. While it cannot be guaranteed that the fishermen are representative of all North Carolina fishermen, information obtained from extensive interviews and detailed telephone questionnaires suggest that the fishermen observed provide a representative description of the *work practices* for these two types of fishing.[25]

Data collection on a freely moving, unstable vessel with limited space and frequent obstruction of lines of sight created many challenges. Researchers were not free to move about for the best view of each worker and were unable to maintain both workers in the video camera frame 100% of the time. Except for two crews that were observed on two different days, the authors observed crews only once and could not fully account for seasonal differences in exposure. Rough days on the water make fishing more challenging for the workers. Other commercial fishing studies have found vessel motion posed musculoskeletal risks to workers,[45] but the authors were unable to account for these exposures in this study. For CABS histograms, load and unload footage from the same 2-man crew were substituted. The limitations described here could attenuate within-worker and between-day variability.

Trunk postures and forces can be difficult to measure accurately.[22,46] Previous studies of trunk postures found direct observations at fixed intervals were correlated with continuous measurement techniques (Spearman's r = 0.62 and 0.57). Although trunk postures can be misclassified at an individual level, on average, the overall percentage of time at various flexion levels is considered reasonably reliable. The authors were unable to directly measure forces involved with some subtasks on the boat (e.g., pulling in the net), so the estimation of the results for those tasks may be subject to misclassification.

For this study, the authors constructed one 3DSSPP model, one LMM simulation, and one lifting index per CABS subtask and generalized them to apply to the fishermen. Specifically, 3DSSPP models for dynamic subtasks represented the peak stress positions. Peak stress models did not represent the full range of potential postures for that task and, when combined with task time, overestimated the duration of ergonomic stress. However, it is expected that the overestimate was not substantial as dynamic subtasks tended to be shorter duration. Alternate models suggested some variability for certain subtasks and these alternate models were incorporated in CABS histograms. For the LMM modeling, the various fishing subtasks were simulated by nonfishermen students in the lab instead of with fishermen in the field. The accuracy of the simulations could not be assessed.

However, the simulations involved straightforward motions that the authors felt could be reasonably replicated by volunteers after watching videotapes. The investigators who had been out on the boats with the fishermen were present during these simulations and asked the subject to repeat any motion that was inconsistent with their observation in the field. Given these limitations, the authors feel the simulation provided a reasonable estimate of trunk kinematics for each task. But it is important to note that these results represent an estimation of the true LMM measurements and do not account for differences in boat and equipment set up or individual technique. LMM simulations were performed for each subtask for up to nine trials, and probability of high-risk group was calculated for each trial. Ranges provided in Table II provide information on the best case for the range of values for this measure.

Finally, it should be noted that there were many subtasks performed by the fishermen that extended the domain of the individual CABS assessment tools. For example, one-handed lifts were common activities on these boats, but a lifting index was still calculated for these subtasks using the NIOSH lifting equation (an application outside the original domain of the equation). While this approach has limited impact on the results of this study due to the relative nature of the comparisons performed, the actual values of the individual assessment measures require cautious interpretation.

CABS and PATH results suggested within-worker and between-and within-day variation. Because CABS models represented only the average low back stress, between-and within-worker variability was underestimated for CABS measures. Quantification of these class variables was limited by a lack of repeated measures on all fishermen. The small sample size, the rarity of 3-man crab crews, the nonexistence of 3-man gill net crews fishing the sound, and only one observed 2-man gill net fishing crew limited the analysis and produced small cell sizes (n = 1) for some combinations of variables.

CONCLUSIONS

Fishing is a unique occupation with a nonindustrial work setting that requires innovative techniques to measure exposures and investigate health risks. These results indicated that the major differences in risk factors for low back stress were due to the type of fishing, crab pot vs. gill net. Workers in either type of fishing spent a lot of time heavy lifting, but the frequent light lifting and static postures convey stress as well. Both crab pot and gill net fishing work involved a combination of routine and nonroutine, or varied, work tasks with non-neutral postures and rare, heavy exertions.

PATH and CABS were well suited for these varied work demands and, in conjunction, provided a more comprehensive picture of lumbar spine stress than either method alone. Refining our understanding of ergonomic exposures will help us quantify peak and cumulative exposures as well as sources of variation helping us explain exposure—outcome relationships in epidemiology studies. Such refinements will also serve to inform empirical ergonomic interventions, such as gear adaptation and modification or crew behavior and work assignments.

These findings support the suggestions of other researchers[17,18,26] that commercial fishermen could make use of mechanical aids for loading and unloading tasks and distribute tasks across crew members within the limits of the established hierarchy of captain and crew member. The type of fishing is less likely to change for an individual, but opportunities exist to develop strategies to reduce risk within a given fishing profession. Tasks with static non-neutral postures such as sorting catch should be considered a priority area for intervention.

Further, the authors identified through qualitative and quantitative studies the need to involve fishermen in identifying, developing, and testing potential utility of interventions. For example, in this study, work surfaces varied on the boats. Some fishermen attached metal plates to the side of the boat and used this as an area to work and rest their gear. Some built low tables, while others simply used a stack of plastic totes. Ensuring an appropriate height for the sorting table on the boat would decrease the amount of time fishermen spend in non-neutral postures but requires participation from the fishermen in order for these changes to fit their work space.

REFERENCES

Driscol, T., G. Ansari, J. Harrison, M. Frommer, and E. Ruck: Traumatic work related fatalities in commercial fishermen in Australia. *Occup. Environ. Med. 51*:612–616 (1994).

Drudi, D.: *Fishing for a Living is Dangerous Work.*In *Compensation and Working Conditions* (CFAR #0025). Washington, D.C.: U.S. Bureau of Labor Statistics, 1998. pp. 3–7.

Loomis, D., D. Richardson, S. Wolf, C. Runyan, and J. Butts: Fatal occupational injuries in a southern state. *Am. J. Epidemiol. 145(12)*:1089– 1099 (1997).

Thomas, T.K., J.M. Lincoln, B.J. Husberg, and G.A. Conway: Is it safe on deck? Fatal and non-fatal workplace injuries among Alaskan commercial fishermen. *Am. J. Ind. Med. 40(6)*:693–702 (2001).

Conway, G.A., J.M. Lincoln, D.S. Hudson, D.M. Bensyl, B.J. Husberg, and J.C. Manwaring: *Surveillance and Prevention of Occupational Injuries in Alaska: A Decade of Progress, 1990–1999.* Cincinnati, Ohio: Alaska Field Station, Division of Safety Research, NIOSH, 2002.

Roberts, S.E.: Occupational mortality in British commercial fishing, 1976–95. *Occup. Environ. Med. 61(1)*:16–23 (2004).

Marshall, S., K. Kucera, D. Loomis, M. McDonald, and H. Lipscomb: Work-related injuries in small scale commercial fishing. *Injury Prevention 10*:217–221 (2004).

Jensen, O.: Work related injuries in Danish fishermen. *Occup. Med. 46*:441–420 (1996).

Jensen, O.: Non-fatal occupational fall and slip injuries among commercial fishermen analyzed by use of the NOMESCO Injury Registration System. *Am. J. Ind. Med. 37*:637–644 (2000).

Loomis, D., S. Marshall, K. Kucera, M. McDonald, and H. Lipscomb: Incidence of non-fatal injuries in a cohort of coastal fishermen [Abstract]. *Occup. Environ. Med. 61*:55 (2004).

Norrish, A., and P. Cryer: Work related injury in New Zealand commercial fishermen. *Br. J. Ind. Med. 47*:726–732 (1990).

Torner, M., and P. Nordling: Occupational injury in Swedish fishery: 1. Analysis of injury statistics. *Occup. Ergon. 2(2)*:81–89 (1999/2000).

Torner, M., G. Blide, H. Eriksson, R. Kadefors, R. Karlsson, and I. Petersen: Musculo-skeletal symptoms as related to working conditions among Swedish professional fishermen. *Appl. Ergon. 19(3)*:191–201 (1988).

Torner, M., C. Zetterberg, T. Hansson, V. Lindell, and R. Kadefors: Musculo-skeletal symptoms and signs and isometric strength among fishermen. *Ergonomics 33(9)*:1155–1170 (1990).

Lipscomb, H., D. Loomis, M. MacDonald, K. Kucera, S. Marshall, and L. Leiming: Musculoskeletal symptoms among commercial fishers in North Carolina. *Appl. Ergon. 35*:417–426 (2004).

Jensen, O., S. Stage, and P. Noer: Classification and coding of commercial fishing injuries by work processes: An experience in the Danish fresh market fishing industry. *Am. J. Ind. Med. 47(6)*:528–537 (2005).

Torner, M., G. Blide, H. Eriksson, R. Kadefors, R. Karlsson, and I. Petersen: Workload and ergonomics measures in Swedish professional fishing. *Appl. Ergon. 19(3)*:202–212 (1988).

Fulmer, S., and B. Buchholz: Ergonomic exposure case studies in Massachusetts fishing vessels. *Am. J. Ind. Med. 42(S2)*:10–18 (2002).

Loomis, D., and H. Kromhout: Exposure variability: Concepts and applications in occupational epidemiology. *Am. J. Ind. Med. 45(1)*:113–122 (2004).

Burdorf, A.: Bias in risk estimates from variability of exposure to postural load on the back in occupational groups. *Scand. J. Work, Environ. Health 19*:50–54 (1993).

Burdorf, A.: Sources of variance in exposure to postural load on the back in occupational groups. *Scand. J. Work, Environ. Health 18(6)*:361–367 (1992).

Burdorf, A., J. Derksen, B. Naaktgeboren, and M. van Riel: Measurement of trunk bending during work by direct observation and continuous measurement. *Appl. Ergon. 23(4)*:263–267 (1992).

Peretz, C., A. Goren, T. Smid, and H. Kromhout: Application of mixed-effects models for exposure assessment. *Ann. Occup. Hyg. 46(1)*:69–77 (2002).

van der Beek, A., J. Kuiper, M. Dawson, A. Burdorf, P. Bongers, and M. Frings-Dresen: Sources of variance in exposure to nonneutral trunk postures in varying work situations. *Scand. J. Work, Environ. Health 21*:215–222 (1995).

McDonald, M., D. Loomis, K. Kucera, and H. Lipscomb: Use of qualitative methods to map job tasks and exposures to occupational hazards for commercial fishermen. *Am. J. Ind. Med. 46*:23–31 (2004).

Mirka, G., G. Shin, K. Kucera, and D. Loomis: Use of CABS methodology to assess biomechanical stress in commercial crab fishermen. *Appl. Ergon. 36*:61–70 (2005).

Hesselman, D., D. Mumford, and C. Wilson: *Annual Fisheries Bulletin: 2004 Commercial and Recreational Statistics*. Morehead City, N.C.: North Carolina Division of Marine Fisheries, Department of Environment and Natural Resources (NCDMF-DENR), 2005. pp. 1–12.

Moe, C., E. Turf, D. Oldach, et al.: Cohort studies of health effects among people exposed to estuarine waters: North Carolina, Virginia, and Maryland. *Environ. Health Perspect. 109(Suppl. 5)*:781–786 (2001).

Buchholz, B., V. Paquet, L. Punnett, D. Lee, and S. Moir: PATH: a work sampling-based approach to ergonomic job analysis for construction and other non-repetitive work. *Appl. Ergon. 27(3)*:177–187 (1996).

Karhu, O., P. Kansi, and I. Kuorinka: Correcting working postures in industry: A practical method for analysis. *Appl. Ergon. 8(4)*:199–201 (1977).

Mirka, G., D. Kelaher, D. Nay, and B. Lawrence: Continuous Assessment of Back Stress (CABS): A new method to quantify low-back stress in jobs with variable biomechanical demands. *Hum. Factors 42(2)*:209–225 (2000).

Waters, T., V. Putz-Anderson, A. Garg, and L. Fine: Revised NIOSH equation for the design and evaluation of manual lifting tasks. *Ergonomics 36*:749–776 (1993).

Marras, W., S. Lavender, S. Leurgans, et al.: Role of dynamic three-dimensional trunk motion in occupationally-related low back disorders: The effect so workplace factors, trunk position, and trunk motion characteristics on risk of injury. *Spine 18(5)*:617–628 (1993).

Chaffin, D., A. Freivalds, and S. Evans: On the validity of an isometric biomechanical model of worker strengths. *IIE Trans. 19*:280–288 (1987).

Chaffin, D., and M. Erig: Three-dimensional biomechanical static strength prediction model sensitivity to postural and anthropometric inaccuracies. *IIE Trans. 23*:215–226 (1991).

Marras, W., S. Lavender, S. Leurgans, et al.: Biomechanical risk factors for occupationally related low back disorders. *Ergonomics 38(2)*:377–410 (1995).

Punnett, L., L. Fine, W. Keyserling, G. Herrin, and D. Chaffin: Back disorders and nonneutral trunk postures of automobile assembly workers. *Scand. J. Work, Environ. Health 17*:337–346 (1991).

Burdorf, A., and G. Sorock: Positive and negative evidence of risk factors for back disorders. *Scand. J. Work, Environ. Health 23*:243–256 (1997).

Riihimaki, H.: Low-back pain, its origin and risk indicators. *Scand. J. Work Environ. Health 17*:81–90 (1991).

Lavender, S., D. Oleske, L. Nicholson, G. Andersson, and J. Hahn: Comparison of five methods used to determine low back disorder risk in a manufacturing environment. *Spine 24(14)*:1441–1448 (1999).

Waters, T., S. Baron, L. Piacitelli, et al.: Evaluation of the revised NIOSH lifting equation: A cross-sectional epidemiologic study. *Spine 24(4)*:386–395 (1999).

Kleinbaum, D.G., L.L. Kupper, K.E. Muller, and A. Nizam: *Applied Regression Analysis and Other Multivariable Methods*, 3rd ed., A. Kugushev (ed.). Pacific Grove, Calif.: Duxbury Press at Brooks/Cole Publishing Company, 1998.

Neumann, W., R. Well, R. Norman, et al.: Comparison of four peak spinal loading exposure measurement methods and their association with low-back pain. *Scand. J. Work, Environ Health 25(5)*:404–409 (1999).

Winkel, J., and S. Mathiassen: Assessment of physical work load in epidemiologic studies: concepts, issues and operational considerations. *Ergonomics 37(6)*:979–988 (1994).

Tomer, M., C. Almstrom, R. Karlsson, and R. Kadefors: Working on a moving surface—A biomechanical analysis of musculo-skeletal load due to ship motions in combination with work. *Ergonomics 37(2)*:345–362 (1994).

Paquet, V.L., L. Punnett, and B. Buchholz: Validity of fixed-interval observations for postural assessment in construction work. *Appl. Ergon. 32(3)*:215–224 (2001).

AIM #2; PAPER #2

TITLE: **Continuous Assessment of Back Stress (CABS) and its Use in Commercial Fishing**

ABSTRACT

Commercial fishing is a job characterized by long hours in an unpredictable, dynamic natural environment and variable demands placed on the musculoskeletal system, requiring strength, coordination, and endurance. The focus of this project was in the quantification of the biomechanical stresses placed on the lumbar spine during the work activities of commercial crab fishermen. The Continuous Assessment of Back Stress (CABS) methodology was used to develop distributions describing the amount of time that each of the crew members on a two- or three-man crabbing crew spend at various levels of low back stress. The results of this analysis, expressed in terms of time-weighted histograms, show significant inter and intra-crewmember variability in the stress measures during regular daily work activities. For the three man crew, the captain has relatively low stress levels throughout the work day, while the mate performs high force (up to 30kg), dynamic exertions while pulling the crab pots from the water up into the boat and high loads (20-40kg) during the loading and unloading of the boat in the morning and evening, respectively. The third man of the crew experiences static awkward postures (forward flexed postures held for up to five minutes at a time) as he sorts and packs the crabs. For the two-man crew, the results show a more even distribution of the high stress activities between the crewmembers. The application of the results of this analysis for prioritization of work tasks for ergonomic intervention is discussed.

INTRODUCTION

Commercial fishing is a job characterized by long hours in an unpredictable, dynamic natural environment. The work tasks demand strength, coordination, and endurance. Much of the existing literature on commercial fishing is concerned with mortality associated with deep sea fishing operations (e.g. Husberg et al., 1998; Lincoln and Conway 1999; Reilly, 1985; Roberts 2004; Schilling, 1993; Schnitzer et al., 1993), with work physiology aspects of this work (e.g. Astrand et al., 1973; Rodahl et al, 1974; Rodahl and Vokac 1977a, 1977b, 1979) or with general safety issues facing the industry (e.g. Bull et al., 2001; Chaing, et al., 1993; Jensen, 2000; Thomas et al., 2001; Törner et al., 1995). These are, without question, important perspectives on the health and safety of commercial fishermen, but it is surprising, based on the physically demanding nature of fishing tasks, the relatively limited number of studies concerned with musculoskeletal disorders in this industry.

There have been a few epidemiological and biomechanical studies that have considered musculoskeletal disorders (MSD) in commercial fishing. From the epidemiological perspective, a study by Moore (1969) of deep-sea fishermen found that strains and sprains were ranked fourth in length of incapacity during fishing after dislocation and fractures, contusions, infected traumas. In a survey-based study Törner et al. (1988a) showed a 12-month symptom prevalence of 52% for the low back, 30% for the shoulder and 21% for the distal upper extremity (distal forearm, wrist, hand, fingers) and based on these results this research team performed more detailed ergonomic assessments of these tasks (Törner et al., 1988b). More recently, Norrish and

Cryer (1990), using insurance data from New Zealand commercial deep-sea fishermen, reported that two thirds of all musculoskeletal injuries were back strains. They found that lifting, lowering, loading, or unloading boxes were responsible for over one third of the injuries and 36% of total reimbursement costs. From a more biomechanical perspective, Törner (1994) considered the influence of the motions of a Swedish sea trawler on musculoskeletal stress and found that the typical motions of a ship of this type were responsible for increased biomechanical stress and further showed that the normal stress associated with manual materials handling activities was compounded by the dynamics of the vessel in rough seas. Fulmer and Buchholz (2002) considered the ergonomic issues facing commercial fishermen as they evaluated lobstering work tasks. They adapted their PATH methodology (Buchholz et al, 1996), to examine these fishing tasks and used the Ovako Work Posture Analyzing System (OWAS) to provide the link between the fisherman's posture and fishing activity to begin to characterize task stress. They characterized lobstering as being composed of repetitive tasks while crewmembers are exposed to awkward trunk postures when hauling up the lobster traps and culling the catch.

The most economically important type of commercial fishing in the estuaries of North Carolina is fishing for blue crabs. Crabs are taken by a number of methods, but the principal one is called crab potting. In this method of crab fishing, bait is placed in a 0.6m x 0.6m x 0.5m cubic wire traps, known as "pots" which are thrown over the side of the boat and are attached with a rope to a buoy. These crab pots are laid in long lines and sit on the floor of estuarine waters. After a day of resting in that location and trapping crabs, the pots are retrieved by the fishermen who drive their boat along this line of buoys to retrieve the catch. In a three-man crew, the captain will drive the boat along the line of buoys and reach out with a hooked pole and snag the rope connecting the buoy to the pot. He will then pull the rope up to the side of the boat and then feed the rope into a device called a pot-puller, a mechanical device that will bring the wire pot up to the side of the boat. The second member of the crew, the mate, will then reach over the side of the boat and manually lift the pot up into the boat. He then opens the trap door and shakes all of the crabs out onto a sorting table, reloads the pot with new bait and throws the pot and buoy back overboard. The third crewmember sorts out these crabs according to size and shell hardness. Each cycle (pot) takes about 30 seconds. In addition to these more cyclical activities that take place out on the water, there are activities that take place on shore before leaving in the morning (loading bait) and upon return at the end of the day (unloading the catch). In a two-man crew similar work activities are performed, but the specific division of work tasks between the individuals are not so well specified and can vary somewhat throughout the workday.

After reviewing some preliminary videotapes of these work activities, it was clear that there was a significant amount of variability in the loading patterns of the musculoskeletal system across work tasks (both across and within individuals), indicating that the Continuous Assessment of Back Stress (CABS) methodology (Mirka et al, 2000) (developed to characterize the biomechanical loading patterns in construction workers in the home building industry) would be an appropriate tool to characterize the stress on the low back throughout the workday. The CABS method employs three established low back stress assessment tools: Revised NIOSH Lifting Equation (NIOSHLE) (Waters et al, 1993); University of Michigan Three-Dimensional Static Strength Prediction Program (3DSSPP) (Chaffin et al, 1987, 1991); and the Ohio State University Lumbar Motion Monitor Model (LMM) (Marras et al, 1993) to quantify stress on a subtask by subtask basis.

The output from the CABS model is a set of histograms describing the amount of time spent by the workers at different levels of low back stress as described by each of the three assessment tools. For the NIOSH Lifting Equation, a histogram describing the relative frequency of lifts at a given level of lifting index is created. For the 3DSSPP model, a similar histogram describing the amount of time at a given level of spine compression is generated. Finally, for the LMM model a histogram describing the relative frequency of lifts at a given level of probability of high-risk group membership (PHRGM) measure is generated. These histograms provide an appreciation both for the peak and average stress values as quantified by each of the three root assessment tools. This information can then be used to help prioritize tasks for ergonomic intervention considering both acute and cumulative stress posed by each sub task. Our objectives in this research were to use this methodology to: 1) quantify these biomechanical stresses in commercial crab fishermen, 2) compare these stresses in workers on a two- and three-man crew and 3) use this information to help identify specific work tasks for intervention.

METHODS

Data Collection

Video footage was captured for a two and three-man crew engaged in crab pot fishing. This video was collected continuously across multiple workdays and analysis of the video was balanced so that it captured all of the work activities of each member of the crews throughout a workday.

Data Analysis and Modeling

Using the CABS method, two aspects of the video data were captured in order to produce time-weighted histograms of back stress levels. First, each crewman's job was broken down into a series of functional subtasks. Some examples of these functional subtasks are "sort crabs", "hook buoy", "lift pot into boat", "load bait on boat", etc. The next step was to analyze the video to create a temporal characterization of the amount of time spent in each of these subtasks. This was accomplished using a computer-based video coding system (OCS Tools™, Triangle Research Collaborative, Inc., Research Triangle Park, N.C.) that allowed the analyst to precisely define the time when the fisherman changed from one subtask to the next and then summarize the time spent in each subtask (this process is described in greater detail in Mirka et al, 2000). The third step was to develop three-dimensional stick figure models for each of the 28 subtasks using the 3DSSPP. For static tasks these stick figure models simply represented the static posture assumed. For the dynamic tasks this stick figure model represented the peak stress position. Using the 3DSSPP assessment tool the spine compression value was estimated (3DSSPPC). These stick figures were then used to approximate the input variables for the NIOSH Revised Lifting Equation (hand locations, asymmetry of posture, etc) for that static posture so that a "Lifting Index" (NIOSHLI) could be created for that task. It should be noted that there were some infrequent one-handed lifts performed by the fishermen and a NIOSHLI was still calculated for this situation using the three-dimensional coordinates of the load, even though it violates a stated limitation of the NIOSH approach. This was necessary to have a complete accounting of the full spectrum of work tasks performed.

The trunk kinematics data necessary for the calculation of the PHRGM measure were collected in a laboratory simulation of these work tasks. The volunteer for this simulation had a good familiarity with the specific work activities. Prior to performing the simulation of a subtask, the volunteer viewed video footage of a fisherman performing the subtask taking note of the posture and motions that the fisherman used to perform the task. As the subject performed these simulated work tasks, he wore the Lumbar Motion Monitor (Marras et al, 1992) to capture the trunk kinematics of the job and then these kinematic data were used to derive the input variables to the OSU LMM model for the calculation of the value of the Probability of High Risk Group Membership (PHRGM). Multiple repetitions of these laboratory simulations were performed to characterize the varied kinematic strategies employed by the crewmember. A PHRGM value was calculated for each trial and the average was used as the assessment for that subtask. Figure 1 shows graphically each of these assessment steps. Using the temporal information from the video analysis along with the output measures from each of the three risk assessment models, histograms of percent time at different levels of low back stress assessments were generated. These histograms were generated for each individual crewmember in both the two- and three-man crew scenario as well as a composite characterization for the whole crew in both scenarios. The latter allowed for a comparison of the total low back loading across the two crew types while the former allowed for an appreciation of how the low back loading was distributed across the individual crewmembers in each crew type.

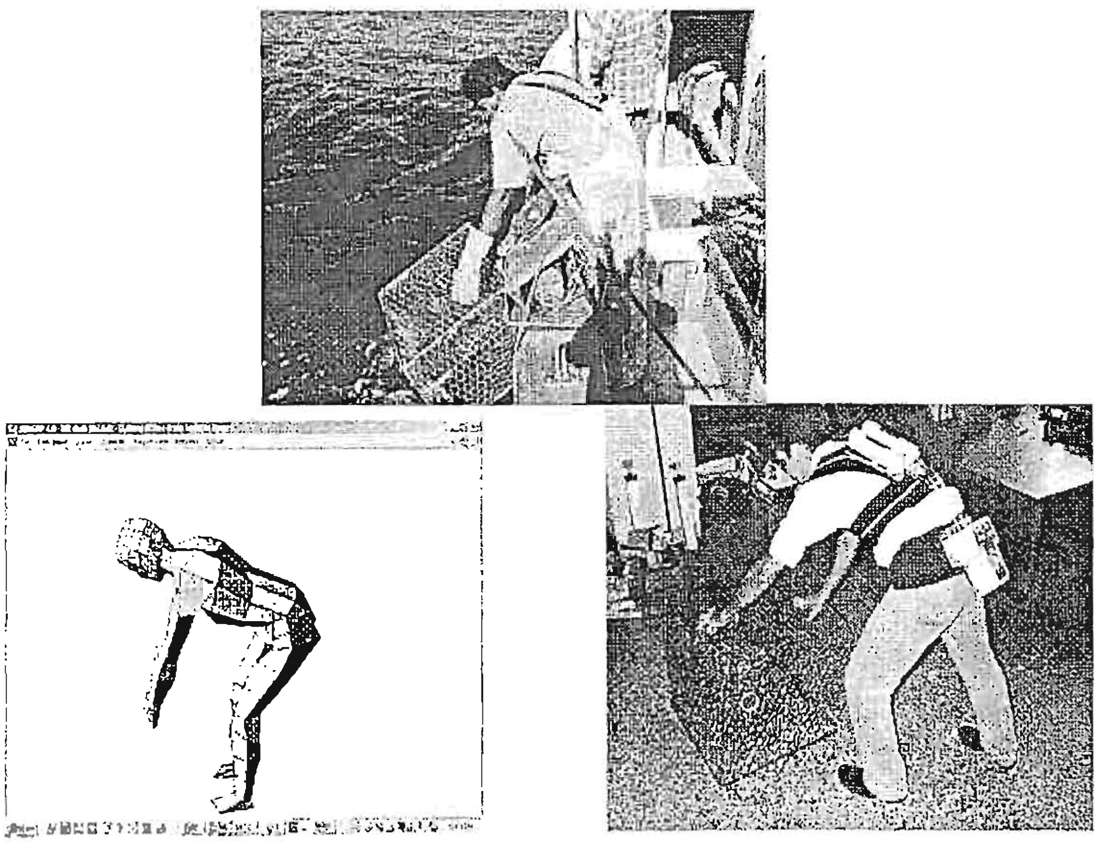


Figure 1. Three phases of task modeling: 1) video capture, 2) stick figure representation for the 3DSSPP™ and NIOSH models, and 3) laboratory LMM simulations. (Pulling crab pot into boat.)

RESULTS

Twenty-eight different subtasks were identified in the CABS analysis of a crabbing operation. Example results from 9 of the 28 subtasks are presented in Table 1. Averaged across crewmembers, the fishermen spent 65% of the workday in upright, unloaded tasks such as upright standing, walking on deck, sitting, etc. While some of these activities have been implicated in the etiology of low back pain (i.e. sitting), these tasks involved little or no external loads and no significant trunk motion and therefore have not been considered in the current analysis. The rest of the time involved some sort of manual material handling activity or non-neutral trunk postures that created biomechanical loading above a "upright standing" baseline level.

Table 1. Sample of subtasks and their assessments from each of the three assessment tools used in the CABS methodology (out of a total of 28 subtasks identified).

	PHRGM (%)	NIOSH LI	Spine Comp (N)
Get Hook	54.5	0.18	824.9
Hook Buoy	61.4	0.66	1503.2
Feed Pot Puller	30.6	0.17	574.3
Load Bait on Boat	84.3	3.30	3197.2
Lift Pot into Boat	79.3	1.23	2429.9
Unload Catch	75.8	5.00	3937.7
Get Bait	58.2	0.48	343.4
Load Bait into Pot	53.0	0.12	719.2
Sort Crabs	41.4	0.09	1832.6

The results of CABS analysis showed significant variability both within and between crewmembers for both the two and three-man crews and also showed important differences in how the stress was distributed across/between crewmembers in three/two man crews. First of all, it is important to note that when summed over all crewmembers, the distributions of total stress values are very similar indicating that the total required loading is very similar between the two crew types (See Figure 2 for the comparison of composite two- and three-man crew assessments). At the most general level, it is interesting to note that percent of time spent at low levels of NIOSHLI was quite high and this is due to the light hand-held loads by these workers for most of the workday. The exception is found in the high NIOSHLI values found for the early morning activities of loading the bait onto the boat and the end of the day activities of unloading the catch. The PHRGM and 3DSSPPC, in contrast, have a much more negative view of this work because of the static awkward postures (3DSSPPC) and dynamic nature (PHRGM) of many of these tasks.

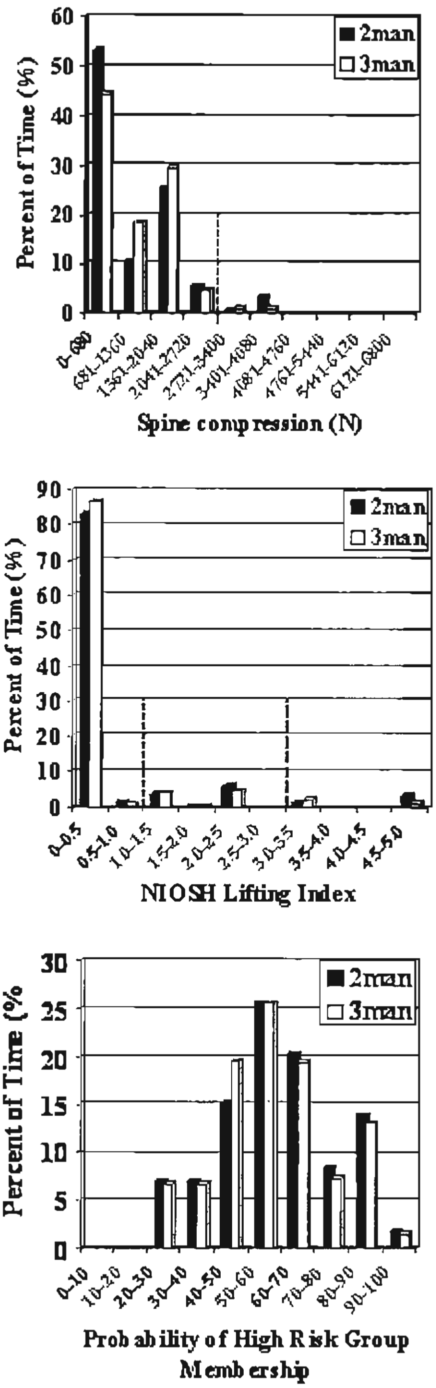


Figure 2. Time-weighted distributions of the three risk assessment models for two and three man crews, averaged across men (vertical dashed lines provide reference to important assessment benchmarks).

When this analysis was performed on a crewmember-by-crewmember basis, differences in the stresses experienced by the individual are considerable. Figures 3-5 allow for a direct comparison of the distribution of the low back stress across the individuals in our three and two man crew. Comparing these distributions qualitatively it is informative to note how the mate on the three man crew had a consistently higher level of low back loading (particularly as described in the NIOSHLI and 3DSSPPC measures) than either the captain or the third man, illustrating the considerable inter-individual differences present between the different workers on this three-man crew. Similar inter-individual differences were not, however, seen in the two-man crew data. Both men seemed to participate equally in the sharing of the high stress kinds of manual materials handling activities throughout the workday. The CABS methodology provides a simple graphical way of elucidating this difference between these two- and three-man crews.

The logic behind the CABS assessment approach revolves around two main concepts. First, that each of the well-established risk assessment tools employed in the model considers the risks posed by physically demanding work from a different perspective. The LMM risk assessment model is unique in that it considers the three-dimensional trunk dynamics of manual material handling task. The Revised NIOSH Lifting Equation, on the other hand, evaluates the static postures assumed at lift-off and set-down of the work task and is particularly sensitive to the magnitude of the hand-held load. Finally, the 3DSSPP is also an evaluation of a static posture assumed during the work activity, but its compression metric is sensitive to non-neutral postures of the torso and does not require a hand-held load. The second concept is that many jobs have considerable variability in the physical demands posed and that this variability needs to be characterized in order to fully appreciate the acute and cumulative biomechanical stress posed by the work activities. This modeling approach proved very valuable in previous ergonomic intervention research for the home building industry (Mirka et. al., 1998; 2000 a, b; 2003) but its utility outside of this industry classification was unproven. Therefore, one of the goals of the current research was to evaluate this modeling approach in tasks other than those for which it was originally developed to assess its generalizability and utility in the commercial fishing industry. The second objective was to use this tool to compare the distribution of low back biomechanical loading across crewmembers in two- and three-man crew crab fishing systems. The last objective was to explore the results of this modeling effort to identify those particular work tasks that receive a high priority for ergonomic intervention.

To address the issue of utility of this modeling technique to this particular industry (and thereby its generalizability beyond the home building industry) we consider the issues of inter- and intra-crewmember variability and the differences in the assessments of the three different assessment tools. The benefit of being able to describe variable biomechanical demands is one of the stated benefits of the CABS modeling approach and the results presented in Figures 3-5 illustrate considerable variability both between crewmembers (e.g. comparing captain vs. mate vs. 3rd man in Figure 3) as well as within a crewmember (e.g. the distribution of the data illustrated for the 1st man in Figure 4) throughout the workday. To illustrate the utility of the CABS modeling approach from the advantages of the multi-assessment tool perspective, one need only to perform a comparison of the assessments for a particular worker across risk assessment tools. For example, the assessment profile of the captain provided in Figure 5 is quite different from that in Figures 3 and 4 indicating that this multi-perspective approach has value in the work tasks of commercial crab pot fishermen. This result, along with the noted within crewmember variability, illustrates that the CABS methodology is a valuable tool in gaining a comprehensive view of the risks posed by these work activities.

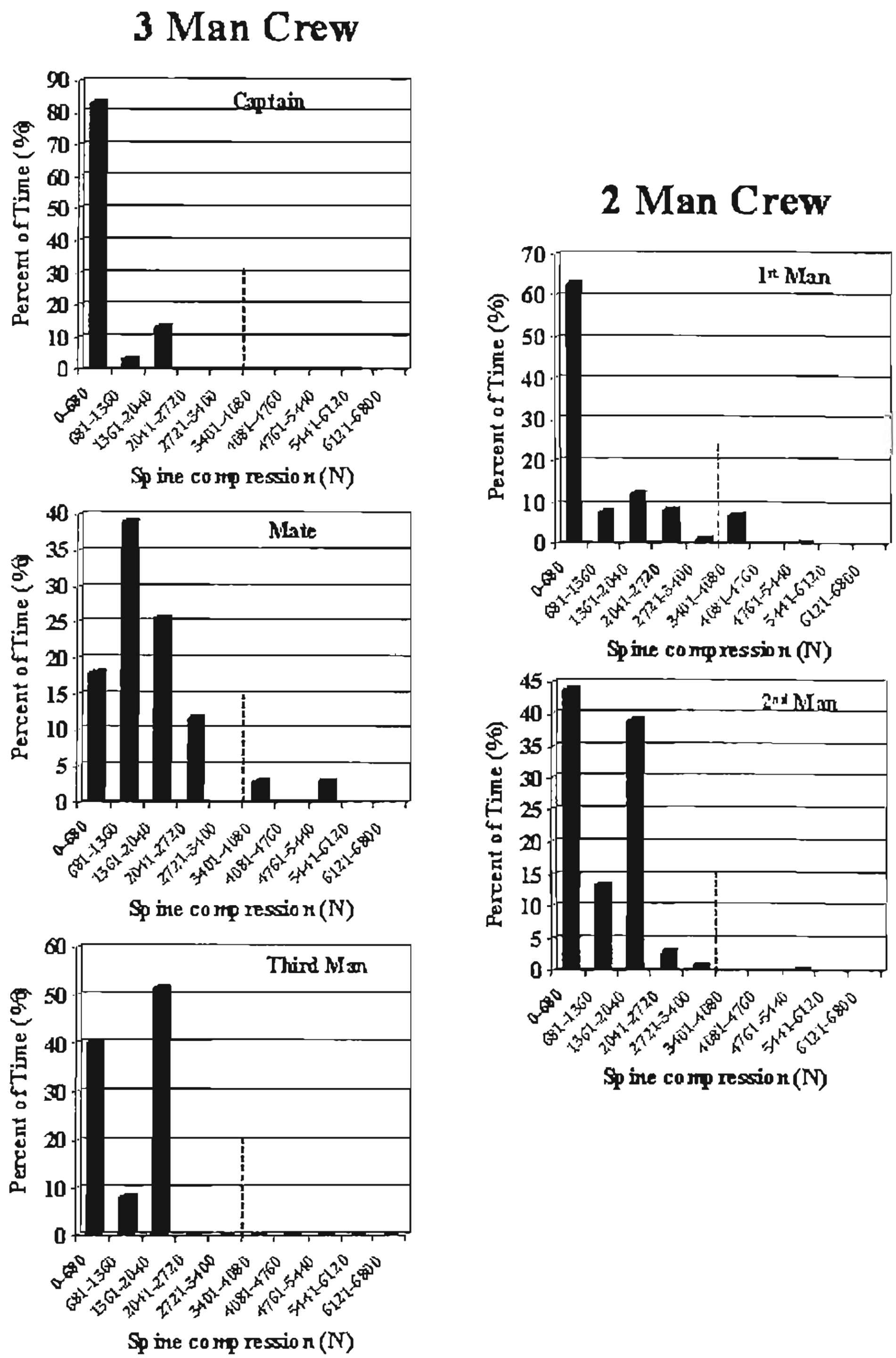


Figure 3. Time-weighted distributions of spine compression by crew member for both the three (right) and two (left) man crews (vertical dashed lines provide reference to important assessment benchmarks).

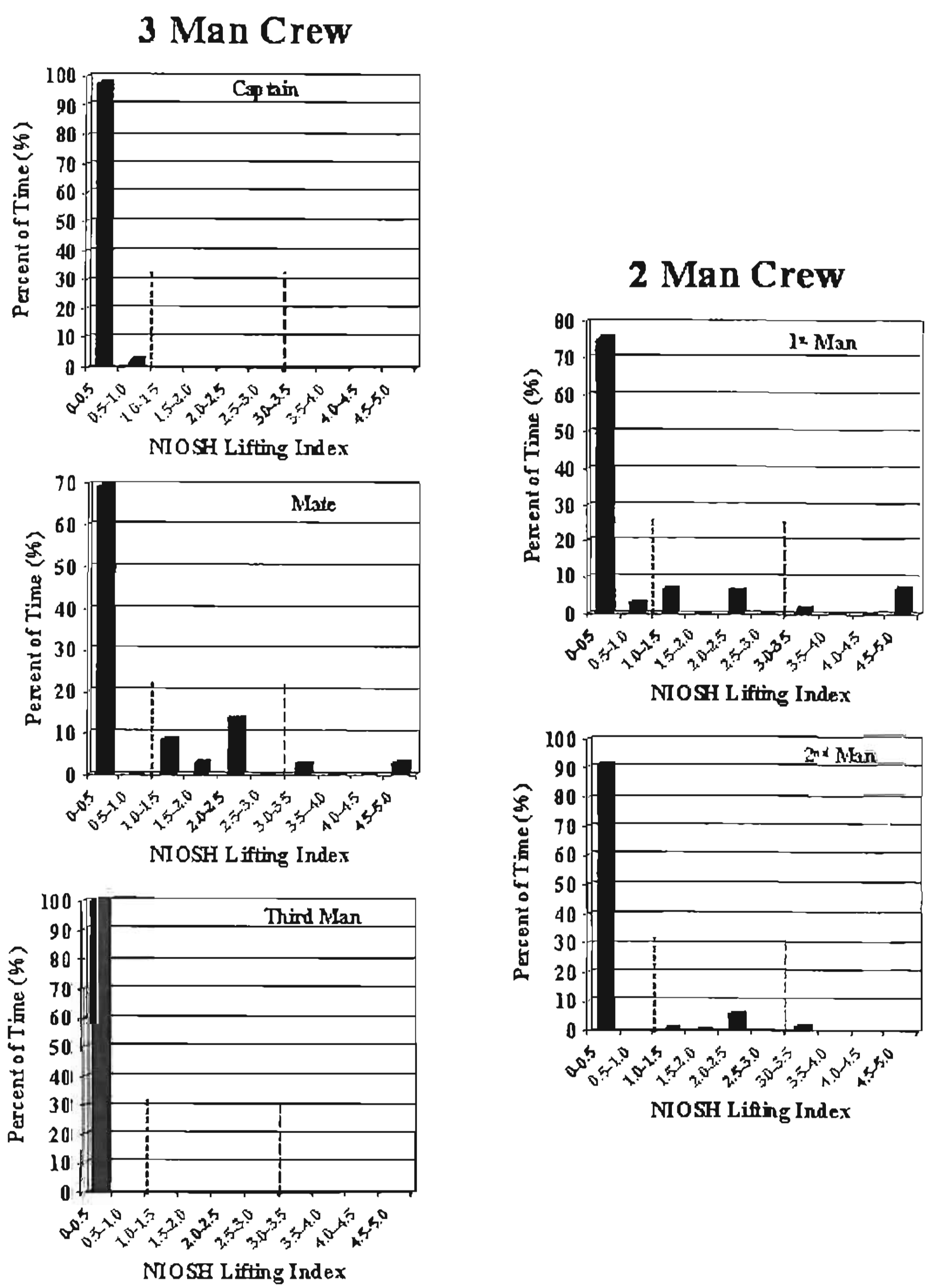


Figure 4. Time-weighted distributions of NIOSH lifting index by crew member for both the three (right) and two (left) man crews (vertical dashed lines provide reference to important assessment benchmarks).

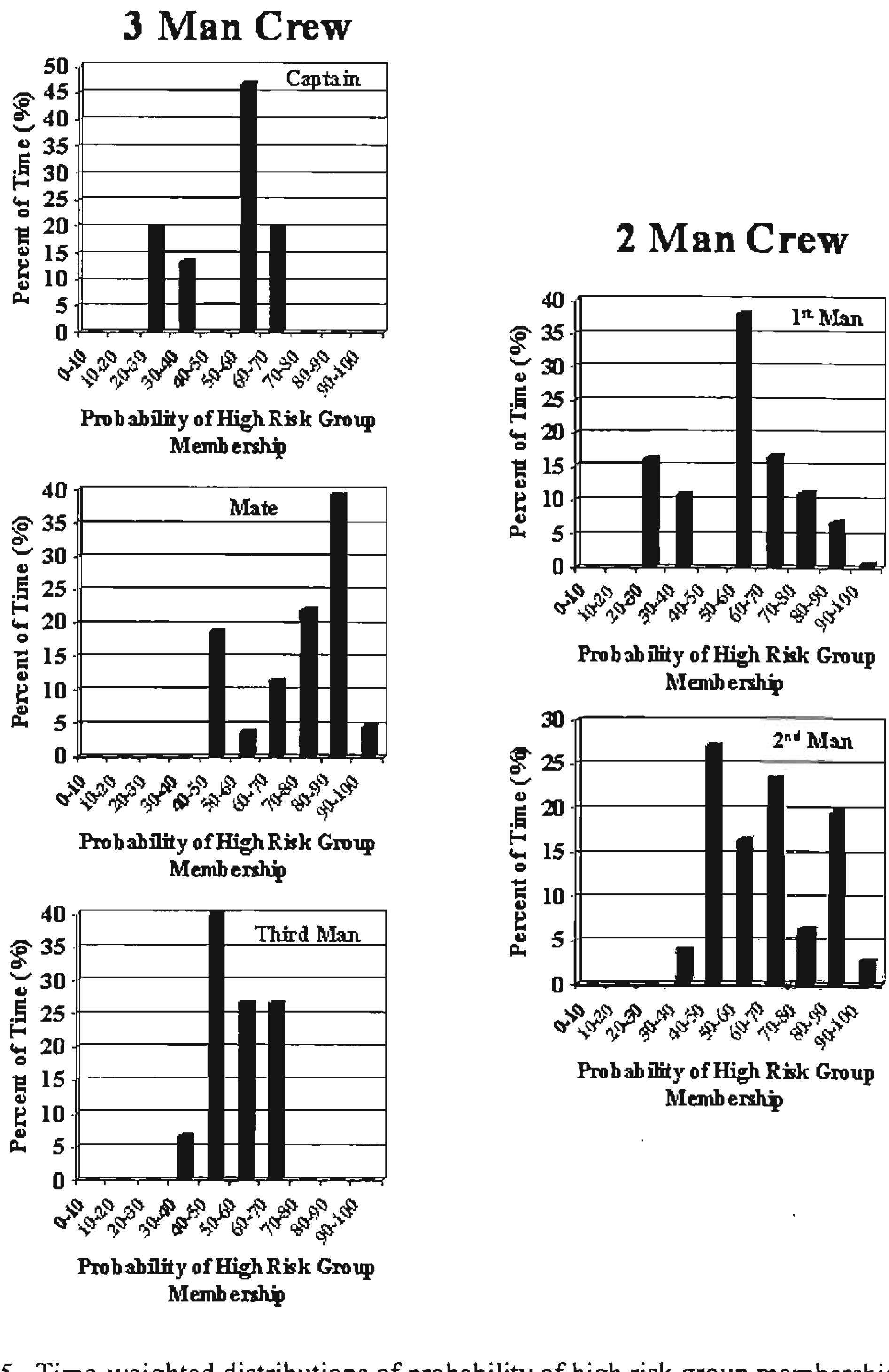


Figure 5. Time-weighted distributions of probability of high risk group membership by crew member for both the three (right) and two (left) man crews.

DISCUSSION

The logic behind the CABS assessment approach revolves around two main concepts. First, that each of the well-established risk assessment tools employed in the model considers the risks posed by physically demanding work from a different perspective. The LMM risk assessment model is unique in that it considers the three-dimensional trunk dynamics of manual material handling task. The Revised NIOSH Lifting Equation, on the other hand, evaluates the static postures assumed at lift-off and set-down of the work task and is particularly sensitive to the magnitude of the hand-held load. Finally, the 3DSSPP is also an evaluation of a static posture assumed during the work activity, but its compression metric is sensitive to non-neutral postures of the torso and does not require a hand-held load. The second concept is that many jobs have considerable variability in the physical demands posed and that this variability needs to be characterized in order to fully appreciate the acute and cumulative biomechanical stress posed by the work activities. This modeling approach proved very valuable in previous ergonomic intervention research for the home building industry (Mirka et. al., 1998; 2000 a, b; 2003) but its utility outside of this industry classification was unproven. Therefore, one of the goals of the current research was to evaluate this modeling approach in tasks other than those for which it was originally developed to assess its generalizability and utility in the commercial fishing industry. The second objective was to use this tool to compare the distribution of low back biomechanical loading across crewmembers in two- and three-man crew crab fishing systems. The last objective was to explore the results of this modeling effort to identify those particular work tasks that receive a high priority for ergonomic intervention.

To address the issue of utility of this modeling technique to this particular industry (and thereby its generalizability beyond the home building industry) we consider the issues of inter- and intra-crewmember variability and the differences in the assessments of the three different assessment tools. The benefit of being able to describe variable biomechanical demands is one of the stated benefits of the CABS modeling approach and the results presented in Figures 3-5 illustrate considerable variability both between crewmembers (e.g. comparing captain vs. mate vs. 3rd man in Figure 3) as well as within a crewmember (e.g. the distribution of the data illustrated for the 1st man in Figure 4) throughout the workday. To illustrate the utility of the CABS modeling approach from the advantages of the multi-assessment tool perspective, one need only to perform a comparison of the assessments for a particular worker across risk assessment tools. For example, the assessment profile of the captain provided in Figure 5 is quite different from that in Figures 3 and 4 indicating that this multi-perspective approach has value in the work tasks of commercial crab pot fishermen. This result, along with the noted within crewmember variability, illustrates that the CABS methodology is a valuable tool in gaining a comprehensive view of the risks posed by these work activities.

Another benefit of using the CABS methodology to assess biomechanical loading in this study is that it provides an opportunity to do a qualitative analysis of the distribution of low back biomechanical loading across crewmembers - specifically comparing a two-man crew with a three-man crew. It should be re-emphasized that the results of the current work only compared the practices of one two-man crew with the practices of one three-man crew. Generalizing these results beyond these particular crews is not appropriate as there is great variability in the way that different crews distribute the various work tasks. But this was not the focus of the current work. From the perspective of the comparison of the two and three-man crews, our goal was to see if this modeling technique is sensitive enough to be able to identify how the biomechanical loading profiles changed with varied partitioning of the work duties of each crewmember in a two and three-man crew. The results of this analysis showed that in the two-man crew studied, there was a more even participation of each crewmember as compared to the three-man crew wherein there was a much more rigid definition of work tasks by job position. This type of data could be useful in developing a more even distribution of the job tasks to make the cumulative loading more equitable across positions. Of course there are challenges associated with seniority and capabilities that must be met, but even with these constraints this information could provide valuable insight into administrative-type interventions to reduce overall risk.

In addition to the possible work methods intervention described above, this assessment method also identified and prioritized a number of subtasks that should be considered for ergonomic intervention. Since the basic tasks performed are similar, if not identical, across crew sizes, this prioritization is valid for both the two and three man crews. Activities found most biomechanically stressful for the lumbar spine were manual materials handling such as lifting and carrying 20 kg baskets filled with crabs during unloading at the end of the day and lifting and lowering 40 kg totes of frozen bait during morning preparations. These MMH activities collectively represented a small fraction of the workday, but are identified as the high-risk activities for acute injury to the low back and are in the far right tail of the distributions for all three of the risk assessment tools. It is also important to note that these high loading conditions occur either first thing in the morning when the crewmember may not be sufficiently warmed up, or late in the day after a full day's work when they are fatigued and stiff from the long trip back from the estuary, making them all the more a point of concern. The second work task that deserves attention is the task of lifting the crab pots from the side of the boat and onto the sorting table. This task is performed often and requires an awkward, dynamic lifting technique and is followed immediately by a lift-tilt-shake sequence where the crabs are emptied from the pot onto the sorting table. The time associated with these tasks are found in the middle of the distributions for the NIOSHLI and 3DSSPPC measures but are at the highest risk levels for the PHRGM measures due to the dynamic awkward lifting postures. Finally, a task that was not specifically identified as particularly problematic by any of the assessment tools was that of sorting crabs. This task was performed with the crewmember bent over the table for extended periods of time while identifying those crabs that were too small and needed to be thrown back. This task generated the peak value in the spine compression distribution for the third man (at about 2200N) (Figure 3). Only when we recognized the long duration for which this static posture was held did this become a concern. Recent research with regard to spine stability and the viscoelastic properties of the passive tissues (e.g. Sbriccoli, 2004; Solomonow, 2004) of the spine during static flexed exertions highlight the potential risk associated with this task and expose a limitation of the CABS method, an issue that we are attempting to address in our on-going basic biomechanical research.

There are several limitations to the current work that should be highlighted, as they may provide ideas for further research in this area. First, the stick figure representations of the 28 subtasks were developed to represent the "average" of the most stressful postures assumed during these subtasks. Certainly, there is significant variability in the ways that the fishermen performed these subtasks and this could have been reflected in the work assessment measures. The goal of the current work was to establish, at a somewhat higher level, the differences in loading between/among the crewmembers. It should be noted, however, that investigation of the intra-crewmember variability for a given subtask might provide additional insight into work technique advances. Second, the trunk dynamics inputs for the PHRGM measure were captured in the laboratory instead of in the field. These data therefore represent an approximation of the true trunk kinematics. Finally, as opposed to more traditional manufacturing environments, natural environments can play a major role in the risks to the musculoskeletal system. Much of the manual materials handling is done on the water, leading to unstable and slippery footing (often leading to leaning against the sides of the vessel), shifting loads (both hand held and body mass loads) and uncontrolled and unfavorable weather conditions (heat, cold, rain, humidity, wind, etc.). Fundamental work by Törner (1994) has illustrated the importance of these environmental issues, unfortunately the CABS methodology is not currently able to directly address these additional stresses. Consideration of the impact of these environmental factors must remain at the forefront during the intervention design process.

CONCLUSIONS

The CABS methodology was found to provide valuable information with regard to the risk factors for low back injury in commercial crab fishermen. The work activities of these individuals were found to have sufficient variability to make use of the "distribution" representation approach of this technique and the characteristics of the work tasks were of the kind that highlighted the benefits of using multiple assessment techniques to get a more comprehensive view of the overall risks. The results of the comparison of the two- and three-man crews profiles further illustrated the potential insight gained by this approach. Finally, a prioritized list of job subtasks to be addressed in ergonomic intervention work was derived from this process:

1- Loading bait onto the boats in the morning
2- Unloading the catch at the end of the day
3- Pulling the crab pots from the water
4- Sorting the crabs

The development and testing of these interventions is the focus of on-going work in our laboratory.

REFERENCES

Astrand I, Fugelli P, Karlsson CG, Vokac Z, Rodahl K (1973) Energy output and work stress in coastal fishing, *Scandinavian Journal Of Clinical & Laboratory Investigation*, 31 (1): 105-113.

Buchholz B, Paquet V, Punnett L, Lee D, Moir S (1996) PATH: A work sampling-based approach to ergonomic job analysis for construction and other non-repetitive work, *Applied Ergonomics*, 27 (3): 177-187.

Bull N, Riise T, and Moen BE (2001) Occupational injuries to fisheries workers in Norway reported to insurance companies from 1991 to 1996, *Occupational Medicine-Oxford*, 51 (5): 299-304.

Chaffin DB and Erig M (1991) Three-dimensional biomechanical static strength prediction model sensitivity to postural and anthropometric inaccuracies, *IIE Transactions*, 23: 215-226.

Chaffin DB, Freivalds A, and Evans SM (1987) On the validity of an isometric biomechanical model of worker strengths, *IIE Transactions*, 19: 280-288

Chiang HC, Ko YC, Chen SS, Yu Hs, Wu TN, Chang PY (1993) Prevalence of shoulder and upper-limb disorders among workers in the fish-processing industry, *Scandinavian Journal Of Work Environment & Health*, 19 (2): 126-131

Fulmer, S. and Buchholz, B. (2002) Ergonomic exposure case studies in Massachusetts fishing vessels, *American Journal of Industrial Medicine*, Supplement 2: 10-18.

Husberg BJ, Conway GA, Moore MA, Johnson MS (1998) Surveillance for nonfatal work-related injuries in Alaska, 1991-1995, *American Journal of Industrial Medicine*, 34 (5): 493-498.

Jensen OC (2000) Non-fatal occupational fall and slip injuries among commercial fishermen analyzed by use of the NOMESCO injury registration system, *American Journal of Industrial Medicine*, 37(6): 637-644.

Lincoln JM, Conway GA (1999) Preventing commercial fishing deaths in Alaska, *Occupational and Environmental Medicine*, 56 (10): 691-695

Marras WS, Fathallah FA, Miller RJ, Davis SW and Mirka GA (1992) Accuracy of a three-dimensional lumbar motion monitor for recording dynamic trunk motion characteristics, *International Journal of Industrial Ergonomics*, 9: 75-87.

Marras WS, Lavender SA, Leurgans S, Rajulu S, Alread G, Fathallah F and Ferguson S, (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*, 18: 617-628.

Mirka GA, Kelaher DP, Nay DT, and Lawrence BM (2000) Continuous assessment of back stress (CABS): A new method to quantify low-back stress in jobs with variable biomechanical demands, *Human Factors*, 42 (2): 209-225.

Mirka GA, Kelaher DP, Nay DT, and Lawrence BM (1998) Assessing low back stress in the construction industry using the Continuous Assessment of Back Stress (CABS) method, Proceedings of the Human Factors and Ergonomics Society 42nd Annual Meeting, 886-890.

Mirka, GA, Kelaher DP, Nay DT, Monroe MJ, and Lutz TJ (2000) Ergonomic interventions for the home building industry, Proceedings of the Human Factors and Ergonomics Society 44th Annual Meeting, 703-706.

Moore SR (1969) Mortality and morbidity of deep sea fishermen sailing from Grimsby in one year, *British Journal Of Industrial Medicine*, 26 (1): 25.

Norrish AE and Cryer PC (1990) Work related injury in New-Zealand commercial fishermen, *British Journal of Industrial Medicine*, 47 (11): 726-732.

Reilly MSJ, (1985) Mortality from occupational accidents to United-Kingdom fishermen 1961-80, *British Journal of Industrial Medicine*, 42 (12): 806-814.

Roberts SE (2004) Occupational mortality in British commercial fishing, 1976-95, *Occupational and Environmental Medicine*, 61 (1): 16-23

Rodahl K, Vokac Z, Fugelli P, Vaage O, Maehlum S (1974) Circulatory strain, estimated energy output and catecholamine excretion in Norwegian coastal fishermen, *Ergonomics*, 17 (5): 585-602.

Rodahl K and Vokac Z (1977a) Work stress in long-line bank fishing, *Scandinavian Journal of Work Environment & Health*, 3 (3): 154-159.

Rodahl K and Vokac Z (1977b) Work stress in Norwegian trawler fishermen, *Ergonomics*, 20 (6): 633-642.

Rodahl K and Vokac Z (1979) The work physiology of fishing, *Psychotherapy and Psychosomatics*, 32 (1-4): 52-59.

Sbriccoli P, Solomonow M, Zhou BH, Baratta RV, Lu Y, Zhu MP, Burger EL (2004) Static load magnitude is a risk factor in the development of cumulative low back disorder, *Muscle & Nerve*, 29 (2): 300-308

Schilling RSF (1993) Hazards of Deep-Sea Fishing, *British Journal of Industrial Medicine*, 50 (11): 962-970.

Schnitzer PG, Landen DD, Russell JC (1993) Occupational injury deaths in Alaska fishing industry, 1980 Through 1988, *American Journal of Public Health*, 83 (5): 685-688.

Solomonow M (2004) Ligaments: a source of work-related musculoskeletal disorders, *Journal of Electromyography and Kinesiology*, 14 (1): 49-60.

Thomas TK, Lincoln JM, Husberg BJ, and Conway GA (2001) Is it safe on deck? Fatal and non-fatal workplace injuries among Alaskan commercial fishermen, *American Journal of Industrial Medicine*, 40 (6): 693-702.

Torner M, Blide G, Eriksson H, Kadefors R, Karlsson R, Petersen I (1988a) Musculoskeletal symptoms as related to working-conditions among Swedish professional fishermen, *Applied Ergonomics*, 19 (3): 191-201.

Torner M, Blide G, Eriksson H, Kadefors R, Karlsson R, Petersen I (1988b) Workload and ergonomics measures in Swedish professional fishing, *Applied Ergonomics*, 19 (3): 202-212.

Torner M, Almstrom C, Karlsson R, Kadefors R (1994) Working on a moving surface - A biomechanical analysis of musculoskeletal load due to ship motions in combination with work, *Ergonomics*, 37 (2): 345-362.

Torner M, Karlsson R, Saethre H, Kadefors R (1995) Analysis of serious occupational accidents in Swedish fishery, *Safety Science*, 21 (2): 93-111.

Waters T, Putz-Anderson V, Garg A, and Fine L, (1993) Revised NIOSH equation for the design and evaluation of manual lifting tasks, *Ergonomics*, 36: 749-776.

AIM #2; PAPER #3

TITLE: **The Effect of a Lower Extremity Kinematic Constraint on Lifting Biomechanics**

ABSTRACT

The opportunity to lean against a stationary barrier (e.g. railing at mid thigh level) during manual materials handling tasks can be seen in many industrial environments, but is particularly prevalent in the commercial fishing industry where fishermen are leaning over this side of the boat to retrieve gear and catch. The effects of this kinematic constraint on low back mechanics are largely unknown. Thirteen participants performed two-handed lifting tasks using both a leaning posture and no leaning posture while their trunk kinematics, muscle activity and ground reaction force were monitored. Results revealed that lifting with the leaning posture required less erector spinae activity (26% MVC vs. 36% MVC) and latissimus dorsi (8% MVC vs. 14% MVC), and less passive tissue moment (24 Nm vs. 43 Nm) compared with the no leaning posture. Peak trunk angular acceleration was lower during the leaning posture (243 deg/s^2 vs. 300 deg/s^2), but the leaning posture also had significantly higher slip potential as measured by the peak A-P ground reaction force (259 N vs. 23 N).

INTRODUCTION

There is considerable evidence that workers in the commercial fishing industry are exposed to many of the recognized risk factors for musculoskeletal disorders (MSDs) of low back including awkward trunk postures, repetitive bending/lifting, hyper-flexion of the trunk, high force lifting exertions, asymmetric lifting and prolonged muscular fatigue. In a study of musculoskeletal symptoms among commercial fishers in North Carolina, low back pain (LBP) was identified as the most highly cited cause of work impairment, holding 17.7% (Lipscomb et al. 2004). Mirka et al. (2005) evaluated the low back stresses during crab fishing activities and noted that manually lifting the crab pots from the water and sorting crabs were two tasks that contributed to the acute and cumulative low back stresses. These results are further supported by a recent survey emphasizing a high risk of low back pain during commercial fishing and pointing to manually lifting objects from outside the boat as particularly stressful (Kucera et al. In review).

There are a variety of strategies that fishermen use to lift the crab pots from the water into the boat. The crab pots used by fishermen in the estuary waters of North Carolina are 60cm x 60cm x 60cm cages made of chicken wire and framed with rebar, weighing between 3 and 12 kgf (depending on catch) and are lifted at a rate of once per minute. These pots are typically pulled up to the side of the boat by a mechanised "pot-puller" and then the fishermen reach over the side of the boat and pull the pot into the boat, where the crabs are shaken out into boxes. A common lifting strategy observed in small-boat crab fishing operations is to lean against the side of the boat (washboard) with one or both thighs when lifting the crab pots from the water. If the fishermen choose not to lean against the washboard, hyper-flexion of trunk and/or asymmetric lifting are typically observed. If the fishermen choose to lean against the washboard, they are not able to use their legs to help with the lifting motion because the knee (and ankle) degrees of freedom in the kinematic chain have been lost. In addition the additional external force provided by the interaction between the thighs and the washboard may initiate additional ground reaction forces (particularly anterior-posterior) that could increase the slip potential. One prior study considered the effect of a kinematics constraint on low back biomechanics during lifting. Shu et al. (2007) evaluated the differences in activation levels of trunk extensor muscles while leaning on a knee support (i.e., loss of degree of freedom of the ankle joint). In this study the participants were asked to maintain a designated trunk flexion angle and then receive and hold a weight that was released into their hands by the experimenter. The kinematic constraint eliminated the motion of the ankle joint but allowed participation of the knee joint. Their results showed that the loss of the degree of freedom at the ankle joint had little effect on the activation level of latissimus dorsi and multifidus muscles during this task. While this previous study provided some information regarding the effect of a kinematic constraint, it was somewhat limited in that it only considered the constraint on the ankle joint – a joint with relatively limited direct impact on low back function. It is felt that limiting the participation of the knee joints through a kinematic constraint may be much more impactful on the function of the low back. The goal of current study was to investigate the effect of a thigh-level kinematic constraint on trunk muscle activation and lifting kinematics.

METHODS

Overview of the study design

The lower extremity kinematic constraint employed in this study was a thigh-level railing simulating a washboard on the side of a small fishing boat (Figure 1). This constraint led to the loss of two degrees of freedom in the kinematic chain (ankle and knee joints). There were two phases in this study: a static phase that involved static weight-holding tasks and a dynamic phase that involved free dynamic lifting tasks. The static trials were designed to understand how the muscles of the lumbar region function under leaning and no leaning conditions. The dynamic trials were designed to quantify the trunk kinematics and ground reaction forces during the leaning and no leaning conditions.

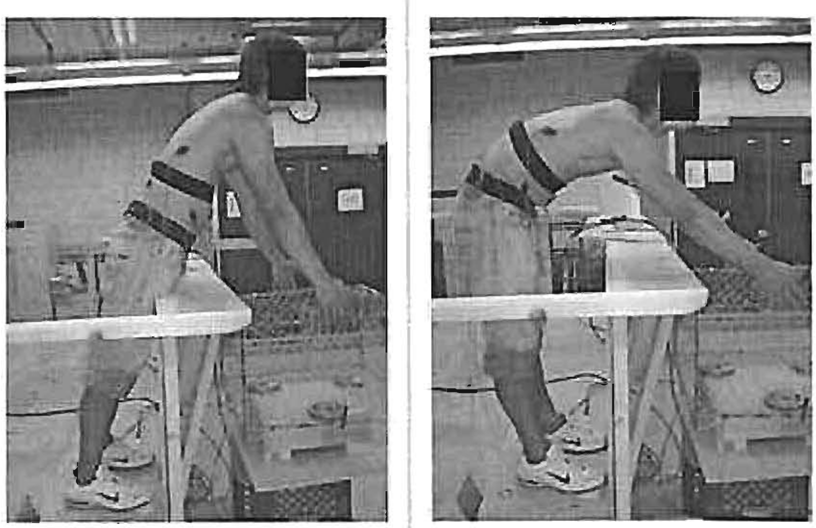


Figure 1. Experimental task: comparison of two lifting postures. Left: leaning, 70 cm height, Right: no leaning, 70 cm height.

Participants
Thirteen male participants were recruited from the university undergraduate and graduate student population of Iowa State University. They did not report any chronic problems or current pain in the low back or lower extremities. Each participant provided written informed consent prior to participation. The average and standard deviation of age, stature and whole body mass of participants were 28.1 yr (4.0), 172.5 cm (2.7), and 71.5 kg (7.2), respectively.

Experimental apparatus
The experimental setup was designed to simulate a boat with 82 cm height rail which served as the lower extremity kinematic constraint during leaning conditions. The load was a 60 cm (L) × 60 cm (W) × 35 cm (H) crab pot with a mass of 9 kg.

Experimental equipment
During the static phase, surface electromyography was used to capture the activities of the ten sampled muscles (Model DE-2.1, Bagnoli™, Delsys, Boston, MA) (data collected at 1024 Hz), and a magnetic-based motion analysis system was used to capture the instantaneous lumbar curvature (The MotionMonitor™, Innovative Sports Training, Chicago, IL) (data collected at 102.4Hz).

During the dynamic phase, the lumbar motion monitor (LMM) (Chattanooga Group Inc., Chattanooga, TN) was used to capture the three-dimensional trunk kinematics (data collected at 60 Hz). A Bertec force platform (Bertec, Columbus, OH) was used to capture ground reaction forces and moments (data collected at 60 Hz).

Experimental Design
Independent variables
A 2 × 3 repeated measure design was employed that had two levels of posture (POSTURE: leaning, no leaning) and three levels of load height (HEIGHT; 85 cm, 70 cm and 55 cm from the ground level) which refer to the height of the hands as the participant grasped the crab pot. There was one replication of each of the six conditions in each phase resulting in twelve trials in both the static and dynamic phases of the experiment. All trials within each phase were completely randomized.
Dependent variables
In the static phase there were six dependent measures and during the dynamic phase there were two dependent measures. The average (across muscle pairs), normalized EMG included five bilateral muscles: erector spinae (ES), latissimus dorsi (LD), rectus abdominis (RA), external oblique (EO) and gastrocnemius (GAS). The extensor moment generated by the passive tissues low back was estimated using the technique of Dolan et al. (1994) (described in more detail in Section 2.7). In the dynamic phase of the experiment, the peak sagittal plane angular acceleration was found from the LMM data and the peak anterior-posterior ground reaction force was found using the force platform. Both were captured during the concentric lifting motion.

Experimental procedures

Upon arrival the experimental procedure was described to the participant and informed consent was obtained. The participants then participated in a five minute warm-up session to prepare the muscles of the low back and lower extremity. The ten surface electrodes were secured on the skin over the selected muscles. The sampling locations for these muscles are as follows: (1) erector spinae: 3.5 cm from the vertebral midline at L2 level, (2) latissimus dorsi: most lateral portion of the muscle at the level of T9, (3) rectus abdominis: 5 cm above the umbilicus and 3 cm lateral to the midline, (4) external oblique: 10 cm from the midline of the abdomen and 4 cm above the ilium at an angle of 45° and (5) gastrocnemius: 2 cm medial from the midline of calf (location of largest muscle mass). The participant completed a series of isometric maximum voluntary contraction (MVC) exertions. For the erector spinae, rectus abdominis and external oblique muscles, a lumbar dynamometer was used to provide a static resistance at the 40 degree trunk flexion angle (Marras and Mirka 1989). For the gastrocnemius muscles, participants were asked to rise on the balls of their feet against manual resistance on their shoulders provided by the experimenter. For latissimus dorsi, participants asked to bend their elbow to 90 degrees, abduct their shoulder to 90 degrees and maximally adduct against manual resistance provided by the experimenter. Two magnetic sensors were then secured on the skin on the midline of the spine - one at the L1 level and the other at the S1 level. The participants were then asked to stand in an upright posture and then to bend forward to a full trunk flexion posture to establish their full sagittal plane range of motion. As they performed this activity data from the magnetic motion sensors on L1 and S1 were captured. This was used to calibrate (express as % of range of motion) the lumbar motion data collected during the experimental trials.

Before beginning the experimental trials, verbal instructions were provided describing the leaning and no leaning postures. Participants were told that during the leaning condition they were to lean against the railing with both thighs and that they should not touch the railing during the no leaning condition (Figure 1). The participants were asked to step on to the force platform and find a comfortable width of their feet. This location of their feet was marked and they were told to keep their feet in this position throughout the experimental trials. The trials in the static phase required that the participant flex the torso and grasp the crab pot and lift it ~5 cm from its resting height and hold that posture for 5s while EMG and magnetic motion sensor data were collected. Between trials, participants were given a rest period of 20 seconds. After completion of all trials, the electrodes and the magnetic sensors were removed.

The second phase began by securing the LMM to the back of the participant and they returned to their position on the force platform. During the lifting trials the participants began in an upright position, bent over to grasp the top of the crab pot and come to an upright position, lifting the pot into the boat. During the trials, both LMM and force platform data were collected. Two trigger signals, one at the point when the participant first touched the crab pot and the other at the end of lifting motion (full upright posture), were also recorded. A rest period of 20 seconds was provided between trials. The LMM was removed and participant was free to leave.

Data processing

The unprocessed EMG data collected during static phase of the experiment were filtered (high-pass 10 Hz, low-pass 500 Hz and notch filtered at 60 Hz and 102.4 Hz and their aliases). For the MVC exertions, the filtered signals were full wave rectified and averaged into 1/8 second windows. The maximum 1/8 second window was indentified for each muscle group and was used as the denominator in order to normalize the EMG data during lifting tasks. For the EMG data collected during experimental trials, the filtered signals were full wave rectified and then averaged over the static weight holding time period. These values were used as the numerator in the normalization process. Finally, the normalized EMG of the right and left muscles of each bilateral pair were averaged.

The sagittal plane angles measured by magnetic sensors placed on L1 and S1 were used to calculate passive moment on low back during static trials. Lumber curvature (LC) was calculated for both the including upright standing and full flexion postures, and the static experimental trials using Equation 1. These values were then used to measure percentage of range of flexion using Equation 2. Finally, this percentage flexion value was used to calculate the passive tissue moment employing by Equation (3) (Dolan et al. 1994).

$$\text{Lumbar curvature (LC in deg)} = \text{Sagittal Angle}_{(L1)} - \text{Sagittal Angle}_{(S1)} \quad (1)$$

$$\text{Percentage Flexion (PF in \%)} = \frac{[LC - LC_{standing}]}{[LC_{fullflexion} - LC_{standing}]} \times 100 \quad (2)$$

$$\text{Passive tissue moment (in Nm)} = 7.97 \times 10^{-5} \times PF^3 + 12.9 \quad (3)$$

Statistical analysis

All statistical analyses in this study were conducted using SAS®. Prior to model analysis, diagnostic tests were performed on the data, including, test for homoscedasticity (Bartlett's Test and Levene's Test) and normality (Anderson-Darling Normality Test) (Montgomery 2001). Dependent variables that violated one or more assumption were transformed so that the ANOVA assumptions were fully satisfied (Montgomery 2001).

Due to the multivariate nature of the data collected in this study, both MANOVA and univariate ANOVA techniques were used. Multivariate analyses of variance (MANOVAs) were conducted on all response measures to control the experiment-wise error rate. Only those independent variables found to be significant in the MANOVA were pursued further in the univariate ANOVA. Post hoc tests employing Bonferroni's method were then performed on these significant main effects. A p-value less than 0.05 were regarded as the standard level of significance of an effect in current study.

RESULTS

The results of MANOVA for average NEMG showed significant effects of POSTURE and HEIGHT, but there was no significant interaction effect between POSTURE and HEIGHT (See Table 1). Accordingly, the interaction effect was not considered in subsequent data analysis. Univariate ANOVAs were conducted on each of the five muscles and revealed a significant effect of POSTURE on all five selected muscle activities. The results showed that a leaning posture requires significantly lower muscle activation as compared to no leaning posture in the trunk extensors, trunk flexors and the gastrocnemius (Figure 2). The effect of HEIGHT was to have ~20% reduction in gastrocnemius activity at the higher load position.

Table 1. MANOVA and ANOVA results for average, normalized EMG.

Independent Variables	MANOVA (Wilks' lamdba)	ANOVA results				
		Dependent Variables				
		ES	LD	RA	EO	GAS
Posture	**p < 0.0001**	**P < 0.0001**	**P < 0.0001**	**P < 0.0001**	**P < 0.0001**	**P < 0.0001**
Height	**p < 0.0001**	p = 0.2753	p = 5628	**p = 0.0003**	p = 0.6261	**p = 0.0002**
Posture × Height	p = 0.0673	N/A	N/A	N/A	N/A	N/A

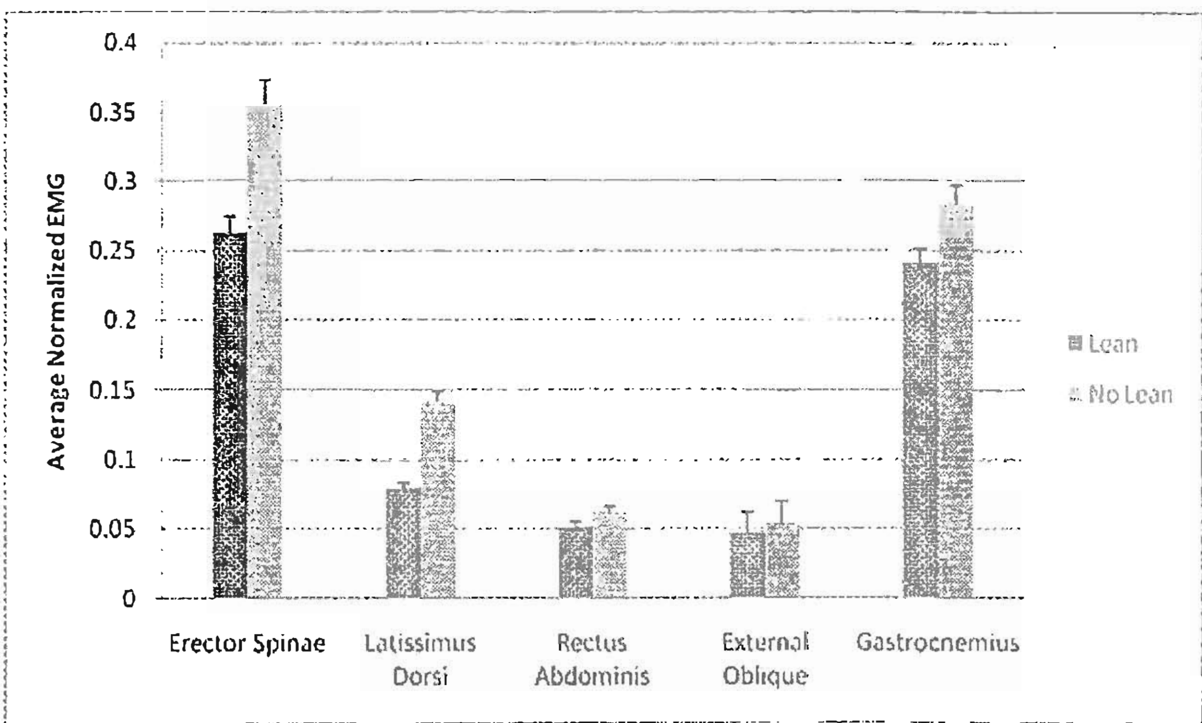


Figure 2. Effect of the POSTURE on NEMG. All differences are statistically significant. (Error bars show standard error.)

The results of the analysis of the passive tissue moment showed a significant effect of POSTURE ($p < 0.0001$), HEIGHT ($p < 0.0001$) and their interaction ($p = 0.0255$) (Figure 3) (simple effects analysis confirmed that both main effects were significant). Percentage of flexion of lumbar spine measured by two motion sensors, one at the L1 level and the other at the S1 level, also showed that the leaning, 55 cm condition stands comparison with the no leaning, 85 cm condition and the no leaning, 70 cm condition (Table 2).

Table 2. Percentage of the flexion range of motion of the lumbar spine seen during the experimental trials (standard errors in parentheses.)

HEIGHT	POSTURE	
	Leaning	No leaning
55 cm	60.55% (3.62)	76.67% (3.73)
70 cm	41.07% (3.17)	68.94% (3.76)
85 cm	25.10% (2.58)	53.81% (2.60)

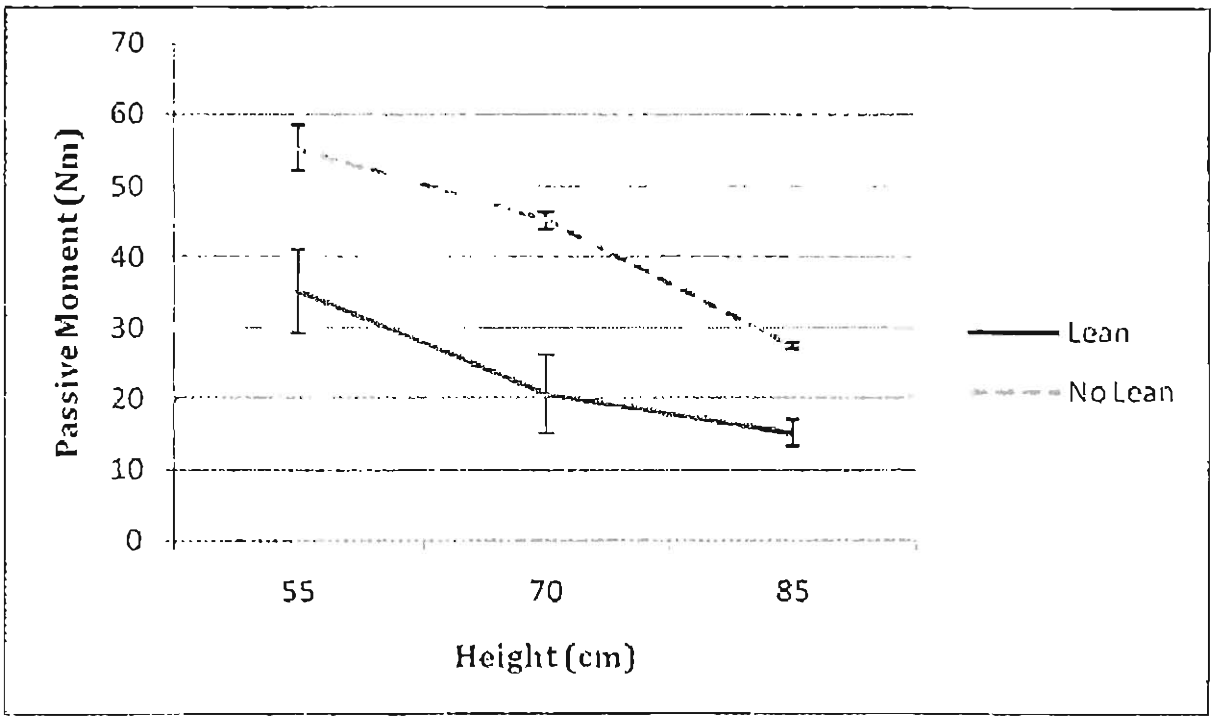


Figure 3. Interaction of POSTURE and HEIGHT on passive tissue moment. (Error bars show standard error.)

Regarding lifting kinematics, the result of ANOVA for angular acceleration in sagittal plane during a concentric lifting motion showed significant effects of POSTURE ($p < 0.0001$), HEIGHT ($p < 0.0001$) and its interaction ($p < 0.0001$) (Figure 4). Simple effects, however, revealed that there is no difference between leaning and no leaning conditions at the height of 55 cm ($p < 0.4319$) but confirmed HEIGHT as a significant main effect ($p<0.0001$).

In regards to the ground reaction force, the results of ANOVA for peak ground reaction force in A-P axis showed significant effects of POSUTRE ($p < 0.0001$), HEIGHT ($p = 0.0004$) and its interaction ($p = 0.0002$) (Figure 5). Simple effects analysis revealed that HEIGHT was not significant in the no lean condition, but confirmed POSTURE as a significant main effect.

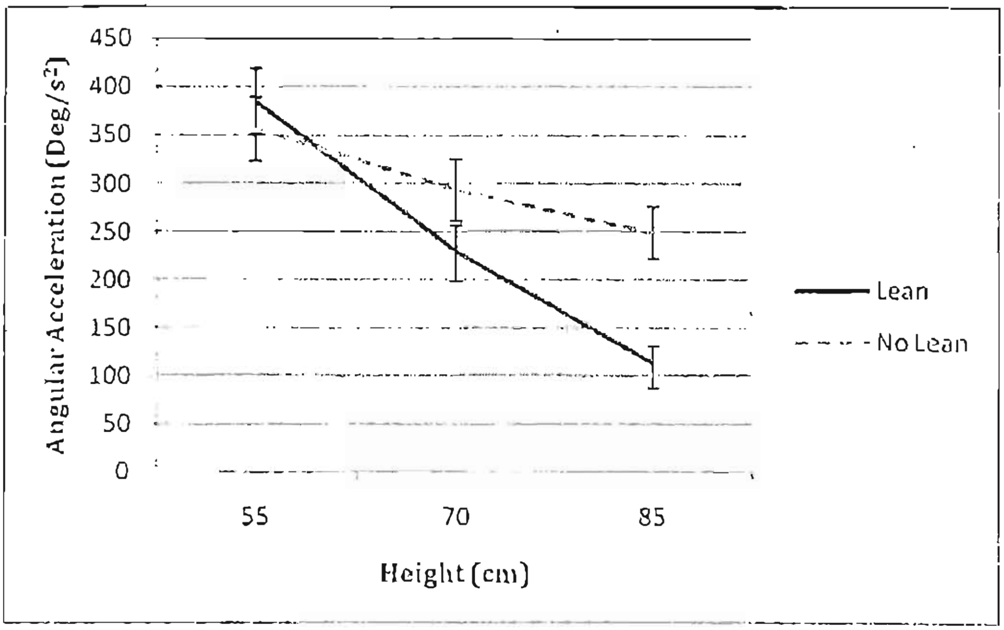


Figure 4. Interaction of POSTURE and HEIGHT on peak sagittal plane angular acceleration. (Error bars show standard error.)

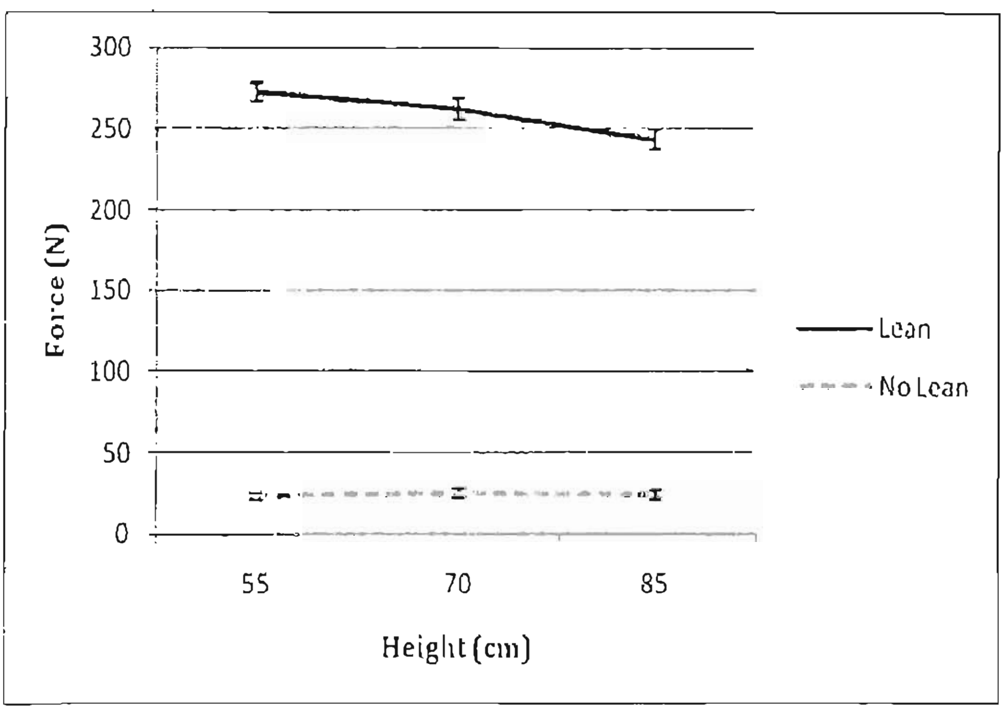


Figure 5. Interaction of POSTURE and HEIGHT on peak anterior ground reaction force. (Error bars show standard error.)

DISCUSSION

Understanding the impact of a leaning posture on low back biomechanics and injury risk can provide valuable insight into possible ergonomic interventions for lifting in many scenarios. The particular scenario considered in the current study was lifting heavy loads from over the side of a small commercial fishing vessel. Quantifying the trunk kinematics through motion analysis, spine loading through electromyography, and slip risk through ground reaction force assessment can provide the type of quantitative data that will indicate whether this would be effective intervention in this particular work environment.

Normalized EMG results showed that the no leaning condition requires significantly greater trunk muscle activities (both agonist and antagonist) than did the leaning condition. The first thing that one notes in evaluating the postures assumed during these static contractions is that the leaning posture allows the pelvis to move anteriorly (Figure 1), thereby moving the fulcrum of the biomechanical system closer to the load and reducing the moment generated by the external load. The second aspect of the results that was not as clear a priori, was that the leaning posture reduced antagonist muscle activity as well. This can be explained by noting that the leaning posture reduced the linear distance between the center of mass of the torso and lowest point of joint freedom and thereby increased the stability of the system over that which would be seen in the free standing (i.e., no leaning) case and a reduced need for significant antagonist muscle activity. Finally, while not part of the active trunk extension mechanism, the moment generated by the passive tissues of the low back were greater under the no leaning condition. The participants were able to keep a more upright trunk posture during the leaning condition, instead of the hyper trunk flexion observed during the no leaning condition for reaching an object (Figure 1). Consequently, the lumbar flexion angle during the leaning condition was significantly smaller than that observed in the no leaning condition resulting in a lower passive tissue moment. With regard to low back loading, it is clear that the leaning posture is superior.

Less clear are the impacts of the leaning posture on lower extremity biomechanics and the resulting slip potential from this technique. The EMG results of gastrocnemius showed a significant (~15%) reduction in the necessary plantar flexion moment during the leaning condition as compared to the no leaning condition, indicating a positive effect of leaning. However, the nature of the leaning posture generated significantly higher anteriorly-directed ground reactions forces than the no leaning condition. The nature of the leaning posture required that the participants push against the barrier with the thighs. With this pushing force comes an equal and opposite ground reaction force that is monotonically related to slip potential. In the current study this anteriorly-directed ground reaction force was shown to vary significantly as a function of load height during the leaning condition with the lower load heights generating the greater anterior shear force. While our laboratory simulation of the process of pulling the crab pots from the ocean had high fidelity in some characteristics, the "deck" surface was clean and dry providing near optimal conditions to reduce slip potential. Realistic fishing conditions (wet surface and other sea-related materials) will reduce this coefficient of friction and may alter the strategies employed by the fishermen performing this lifting task.

Expanding the results of the current study to a more general recommendation for broader industry applications should be done with care. It is clear that leaning against a solid barrier will move the lifter closer to the load and thereby reduce the external moment of the load. Further, it appears from the results of the current study that this will likewise reduce the antagonist activity in the trunk, presumably because of the greater stability the leaning posture provides. Caution should be taken, however, when considering the slip potential that this leaning posture generates. Our results indicate that the peak A-P ground reaction force is significantly greater with the leaning posture and it is also a function of load height. The increased A-P ground reaction forces can be counteracted by providing high friction floor surface or vertical stabilizers in the floor against which the lifters feet can push to accomplish the lift in a safe manner. Therefore as one considers the effectiveness of a leaning strategy to reduce low back injury risk, one should consider environmental factors when developing the leaning strategy as an effective ergonomic intervention strategy.

CONCLUSIONS

This study considered the effects of a leaning posture on spine biomechanics and lower extremity slip potential. Our results showed that the leaning lifting strategy provides some biomechanical benefits over the no leaning lifting strategy. First, both active and passive components of low back revealed significantly lower levels during the leaning condition. Second, plantar flexion torque (as estimated by the gastrocnemius muscles activation level) was smaller in the leaning condition leading to reduced levels of fatigue of these muscles. Third, the leaning condition had slower trunk acceleration, so the leaning condition may have smaller spinal forces and moments as compared to the no leaning condition. In addition to these positive effects, there was one important drawback of the leaning posture. This posture generated greater ground forces in posterior direction (anteriorly directed ground reaction force), so there is potential, under certain environmental conditions, for the leaning posture to increase slip potential. While the experiment conducted to evaluate the leaning posture was a simulation of a task observed in the commercial fishing industry, the results of the study can be applied, with some caveats to many industrial environments when lifting occurs. The study has shown that environmental factors to be considered in these other applications are the coefficient of friction of the ground surface as well as the height of the object of be lifted. The improvement in the biomechanics of the low back seem to be independent of these variables, but the risk of slip and fall are very much impacted by these environmental factors.

REFERENCES

Dolan, P., Mannion, A.F., and Adams, M.A., 1994. Passive tissues help the back muscles to generate extensor moments during lifting. *Journal of Biomechanics*, 27, 1077–1085.

Lipscomb, H.J., et al., 2004. Musculoskeletal symptoms among commercial fishers in North Carolina. Applied Ergonomics, 35, 417-426.

Kucera, K.L. and McDonald, M.A., In Review. Occupational stressors identified by small-scale, independent commercial crab pot fishermen. *Journal of Safety Research.*

Marras, W.S., and Mirka, G.A., 1989. Trunk strength during asymmetric trunk motion. Human Factors, 31, 667–677.

Mirka, G.A, *et al.*, 2005. Use of the CABS methodology to assess biomechanical stress in commercial crab fishermen. *Applied Ergonomics*, 36, 61-70.

Montgomery, D.C., 2001. *Design and Analysis of Experiments*. 5th ed., New York: John Wiley & Sons, Inc.

Shu, Y., *et al.*, 2007. The effect of a knee support on the biomechanical response of the low back. *Journal of Applied Biomechanics*, 23, 275-281.

AIM #2; PAPER #4

TITLE: **The Effect of Sinusoidal Rolling Ground Motion on Lifting Biomechanics**

ABSTRACT

The objective of this study was to quantify the effects of ground surface motion on the biomechanical responses of a person performing a lifting task. A boat motion simulator (BMS) was built to provide a sinusoidal ground motion (simultaneous vertical linear translation and a roll angular displacement) that simulates the deck motion on a small fishing boat. Sixteen subjects performed lifting, lowering and static holding tasks under conditions of two levels of mass (5 and 10kg) and five ground moving conditions. Each ground moving condition was specified by its ground angular displacement and instantaneous vertical acceleration: A): $+6^o$ & $-0.54\ m/s^2$; B): $+3^o$ & $-0.27\ m/s^2$; C): 0^o & $0 m/s^2$; D): -3^o & $0.27\ m/s^2$; and E): -6^o & $0.54\ m/s^2$. As they performed these tasks, trunk kinematics were captured using the lumbar motion monitor and trunk muscle activities were evaluated through surface electromyography. The results showed that peak sagittal plane angular acceleration was significantly higher in Condition A than in Conditions C, D and E ($698 deg/s^2$ vs. 612-$617 deg/s^2$) while peak sagittal plane angular deceleration during lowering was significantly higher in moving conditions (conditions A and E) than in the stationary condition C (538-$542 deg/s^2$ vs. $487 deg/s^2$). The EMG results indicate that the boat motions tend to amplify the effects of the slant of the lifting surface and the external oblique musculature plays an important role in stabilizing the torso during these dynamic lifting tasks.

INTRODUCTION

On-ship manual materials handling tasks have been shown to be associated with high prevalence of musculoskeletal problems in the fishing industry (Driscol et al., 1994; Thomas et al., 2001; Conway et al., 2002; Roberts, 2004; Jensen, 2000; Norrish and Cryer, 1990; Torner et al., 1988; Lipscomb et al, 2004). Heavy manual material handling is a normal task fishermen perform on ship (Kucera et al. 2008) and was reported by the fishermen as a main reason for high workload (Torner et al., 1988). Torner et al. (1988) reported a one-year prevalence rate of 70% for musculoskeletal problems among fishermen in Sweden, and Lipscomb et al. (2004) reported a one-year prevalence rate of 83.3% for musculoskeletal symptoms in North Carolina fishermen in the United States.

Working in a moving environment (e.g. on a ship) can create multiple problems for workers, such as motion sickness, loss of balance, physical fatigue and reduction of performance (Wertheim, 1998). Among these problems, balance problems and physical fatigue can be related with on ship manual materials handling work. Wertheim et al. (2002) evaluated maximum oxygen consumption while participants performed a graded exercise test on a cycle ergometer under stable conditions and those that would be experienced in three, dynamic ground motion conditions (on a small coast guard boat, random 3-D angular motions and on a ship on the open sea). These authors found that maximum oxygen consumption was reduced by 6-10% when participants were working under a moving environment. In an earlier study, these same authors showed that the oxygen consumption of a particular task increased by 16% under a moving surface environment. Combining these two results, these authors suggest that this would result in a decrease of 50% to the time to exhaustion for that particular task.

A number of studies have been conducted to quantify the effects of ship motion on the biomechanical responses during on-ship manual material handling tasks. Torner et al. (1994) investigated the effect of ship motion on low back loading during lifting. In that study researchers had one subject perform standing, holding and repetitive lifting at the motion center of a trawler (length 24 m, gross weight 164 ton with motion period approximately 8 s). They used a two-dimensional biomechanical model to calculate joint moment and L4/L5 level spine compression force during lifting. Their results showed that these ship motions can increase spine compression by up to 40%. In another study of effects of ship acceleration on low back stress, Kingma et al. (2003) performed a simulation study that mathematically applied ship motion data (gathered from two locations on a 120m frigate under two sea-state conditions) to a dataset of lifting and pulling kinematics data that were collected under stationary conditions. Their simulation results suggested that unfavorable timing of lifting caused a moderate (up to 15%) increase in low back moments. Also, from their calculations, Kingma et al. (2003) showed that the different directions of ship acceleration have different impacts on the low back moments. This simulation study was based on an assumption that workers would use the same lifting technique and body kinematics on a moving ship as were observed on stationary ground. The validity of this assumption remains untested.

A follow up on-ship investigation by Faber et al. (2008) supported some of the conclusions reported by Kingma et al. (2003). Faber et al. (2008) investigated the effect of ship motion on spinal moments and compression forces during lifting under different motion conditions on a military vessel (42 m long and 9 m wide, motion period was about five seconds). They also compared the effect of free pace lifting and constrained pace lifting on spinal loading. Results from that study suggested that vertical acceleration of the ground surface increased net moment by 10.1% per m/s^2 of average absolute value of z-acceleration, and this acceleration has a greater impact than other directions of linear accelerations. They also showed that free pace lifting did not reduce the low back loading compared to the constrained pace lifting.

There are several studies that have investigated the effect of ground angular motion during lifting (Matthews et al., 2007 and Holmes et al., 2008). Matthews et al. (2007) investigated the effect of three ground angular motion conditions (roll, quartering, and pitch) on trunk kinetic and kinematics during lifting. In this study the ground motion was provided by an in-lab boat motion simulator executing an angular motion profile derived from a 45 ft long vessel experiencing 7 m waves with 5-10 s periods, and these responses were compared with those in a no-motion condition. Their results showed a significant decrease (~30%) in maximal trunk extension velocity under the roll (rotation about the anterior posterior axis) ground moving conditions as compared to the no-motion environment. Pitch motion (rotation about medial-lateral axis) was found to be the most difficult condition to maintain stability.

The rolling motion of a boat (i.e. rotation about the anterior–posterior axis) generates lower extremity postures and orientations similar to the postures seen in a study of slanted ground surfaces considered in Jiang et al., (2005). In this study, the authors investigated the effect of laterally slanted ground on back extensor muscle activities during static weight holding tasks. Four slanted ground angles (0°, 10°, 20° and 30°) were tested in that study and their results showed that both the right and left erector spinae showed increased activity with increased slant angle, with the contralateral muscle showing a more rapid increase in activity with greater slant angles. In this study, significant changes of muscle activation happened only in relatively large slanted angles (20^{o} and 30^{o}). The instability created with these slant angles resulted in higher levels of co-contraction, presumably to increase the safety of the lifting task.

While there have been a number of studies that have attempted to address the relationship between deck motions and biomechanical responses during lifting on a ship, these studies typically have considered the ship motions experienced by large vessels on the high seas. The effects of the ground motions that workers on a smaller boat experience in shallow water remain largely unknown. This is important because sea surface motion varies significantly between the sea surface far from shore and that experienced close to shore. When waves approach the shore the reduced water depth causes the wave steepness to increase (Trujillo and Thurman, 2008). Also large ships with more mass will experience a longer period of motion than smaller fishing boat due to their difference in total mass and inherent natural frequency. Most of the fishermen in the crab fishing and the gill net fishing industries work on relatively small fishing boat close to shore. Both the size of their boat and their proximity to shore make the application of the results from the research on deep sea vessels difficult to interpret relative to these smaller fishing vessels.

The purpose of current study was to quantify the effects of amplitude of sinusoid wave motion that would be typical of small craft motions (generating both vertical accelerations and angular displacements of the deck surface) on trunk muscle activation and trunk kinematics during lifting, lowering and weight holding tasks. This research was conducted on a boat motion simulator (BMS) which simulates the motion of a smaller sized boat fishermen use in the crab and gill net fishing industries.

METHODS

Participants

Sixteen subjects with average age 25 (SD 3.6) stature 179 cm (SD 6.1) and total body mass 70 kg (SD 7.5) were recruited from the student population of Iowa State University and provided written informed consent before participation. All subjects were free from any chronic and current low back pain.

Experimental Apparatus

A boat motion simulator (floor surface 3.7 m long × 1.8 m wide) was built to provide a controlled moving environment for subjects to perform lifting tasks (Figure 1). The simulator has the ability to rock from side to side by manpower and provides a sinusoidal vertical and angular movement of the BMS which simulates the deck motion on a small fishing boat. The BMS moves with a natural period of 1.6 seconds. Two plastic crates (33 cm×33 cm×28 cm) with total mass of 5kg and 10kg were the loads to be lifted in this experiment. The crate had good handles and the height of handles was approximately 25 cm.

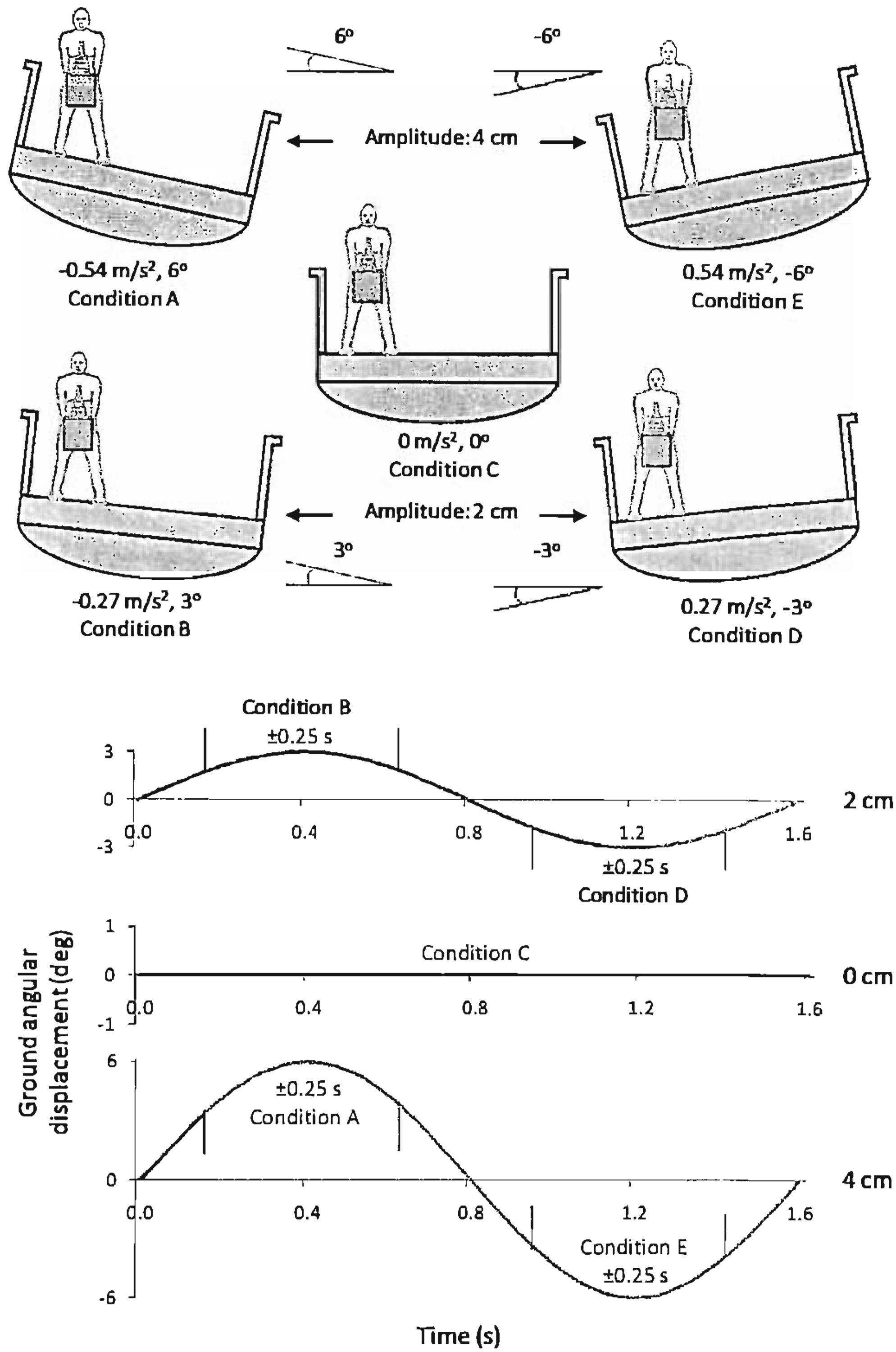


Figure 1: Coronal plane (front) view of the experimental set up and demonstration of the five ground surface conditions.

Data Collection Apparatus

Surface electromyography (EMG) was used to capture muscle activity levels. Six bi-polar electrodes (Model DE-2.1, Bagnoli™ Delsys) were attached to the skin over the bilateral muscle groups: erector spinae, rectus abdominis, and external oblique and these data were collected at 1024 Hz. The Lumber Motion Monitor (LMM) (Chattanooga Group Inc., TN) was attached along the back of the subject to capture the trunk kinematic (Marras et al. 1992). The LMM provided 60 Hz continuous measurement of angular position, velocity and acceleration in three cardinal planes of motion: sagittal, coronal and transverse plane.

Independent Variables

Two independent variables were considered in this experiment: MASS and CONDITION. MASS was the total mass of the load being lifted and had two levels: 5 kg; 10 kg. CONDITION referred to the ground condition (i.e. the instantaneous angular orientation and the instantaneous linear vertical acceleration) and had five levels: A): 6°, -0.54 m/s^2; B): 3°, -0.27 m/s^2; C): 0°, 0 m/s^2; D): -3°, 0.27 m/s^2 and E): -6°, 0.54 m/s^2 where condition A and B represent conditions where the ground surface is at the top of the range of motion and conditions D and E represent conditions where the ground surface is a the bottom of the range of motion (Figure 1.) The vertical acceleration profile of the BMS motion can be simplified as a simple harmonic motion and the instantaneous vertical acceleration can be calculated by using Equation 1. A and T represent motion amplitude and period respectively, and this equation is used to calculate the instantaneous dynamic acceleration rate starting from the peak of BMS motion. More specifically conditions A and E were when the BMS moved with a 4 cm amplitude and 1.6 second period (the natural period of the BMS) and the accelerations at either the peak or the trough of the motion were -0.54 m/s^2 and 0.54 m/s^2, respectively. Conditions B and D were similar to A and E but with a 2cm amplitude (-0.27 m/s^2, 0.27 m/s^2). In condition C the BMS was static so acceleration was 0 m/s^2.

$$Acc(t) = -A \times (2\pi / T)^2 \times \cos(2\pi t / T) \qquad \text{[Eq. 1]}$$

Dependent Variables

For the dynamic lifting tasks, four trunk kinematic variables were considered. Both peak sagittal angle (greatest trunk flexion) during the concentric lifting motion and peak sagittal angle (also greatest trunk flexion) during the eccentric lowering motion provided postural response information. Peak sagittal plane angular acceleration during the lifting motion and peak sagittal plane angular deceleration during the lowering motion provided important insight into the motion strategies employed by the participants. For the static weight-holding tasks, the normalized (to maximum) EMG response from the six bilateral muscles Right Erector Spinae (RES), Left Erector Spinae (LES), Right Rectus Abdominis (RRA), Left Rectus Abdominis (LRA), Right External Oblique (REO) and Left External Oblique (LEO) were the dependent variables. It must be clarified that "dynamic lifting tasks" and "static weight-holding tasks" refer to the motion required of the participant, not the motion of the boat. (i.e. participants performed the static weight-holding tasks both when the BMS was moving and when it was stationary and the participants performed the dynamic lifting tasks both when the BMS was stationary and when it was moving.)

Experimental procedure

Upon arrival participants were provided a brief introduction to the experiment and then written informed consent was obtained. Subjects were guided through a five minute warm-up routine to stretch and prepare the muscles of the low back, upper and lower extremities. They were then fitted with six bi-polar surface EMG electrodes on the skin over three bilateral muscle groups (erector spinae, rectus abdominal and external oblique). A series of maximum voluntary contractions (MVC) were performed by using the static resistance provided by an isokinetic dynamometer (Mirka and Marras, 1993). MVC EMG for the trunk extensor (erector spinae) and flexors (rectus abdominis and external oblique) were captured by having subjects assume a sagittal symmetric, ~30° forward flexion trunk angle and perform extension or flexion task respectively against the dynamometer resistance. After these MVC trials, the LMM was secured to the low back of the participants.

The participant then moved to the BMS where they were asked to center themselves on a fixed location on the deck of the BMS, 50 cm away from the midline of the deck. Subjects were always facing toward the bow of the BMS with their feet width set at 120% of their shoulder width (this is a location and orientation of manual materials handlers often seen on small fishing boats.) The crate was set on the deck 50 cm from the midline of the boat.

In the experimental trials, the participants were asked to perform three repetitions of each load lifting and load lowering task in 30 seconds. For individual trials, the BMS moved at the designated amplitude (0cm, 2cm or 4cm) to create different lifting conditions (Figure 1.) The lifting task required the subject to first stand in a neutral upright posture on the deck of BMS, bend over grasp the load and lift it up to the upright standing posture. The lowering task was performed following each lifting task and the subject started from the ending posture of lifting task, they bent over, lowering the load down to the deck, released the load and came back to upright posture again. The starting time of every lifting and lowering task was cued by experimenter by saying "Go". The timing of this "Go" command was such that the lifter was performing the task at the designated position (peak or trough of the boat motion). Given the critical importance of the lifting/lowering motion occurring at just the right instant within the context of the overall boat motion, some training between the lifter and the experimenter was necessary so that when the experimenter said "Go" this produced the lifting/lowering motion in the correct time interval for achieving the designated experimental condition. After completing the three repetitions of the load lifting and lowering tasks, participants then performed a static weight-holding task (boat continued moving at the designated amplitude.) This task required subjects to hold the load with the handles at their mid-thigh level for six seconds. This mid-thigh load height was chosen so that subjects had to flex their torso to activate the erector spinae muscles, but avoid the effect of flexion relaxation that would come with more severe trunk flexion angle. During data collection, an event marker was pressed each time the boat reached the trough position and this provided useful information regarding boat motion that was used during data processing to help identify lifts occurring outside of the designated motion windows.

The combination of two levels of MASS and five levels of CONDITION resulted in ten different lifting scenarios. Two repetitions for each of the ten scenarios were performed, resulting in 20 lifting trials. The order of presentation of the experimental conditions was completely randomized.

Data Processing

The event marker data was used as the time for each trough point of the BMS motion, and the midpoint between two successive troughs was identified as the peak of the boat motion. For the dynamic lifting and lowering tasks, the timing of when the experimenter said "Go" and when the lifting/lowering task was performed was not always perfect. Therefore it was necessary to perform a data quality screening test on each lift. The technique employed was to use the LMM data to identify when the peak trunk extension acceleration occurred during the lifting task (or the peak sagittal deceleration during the lowering task) and evaluate the timing of this peak relative to the ideal peak (or trough) from the event marker data. If the peak sagittal acceleration (or deceleration) occurred within ±0.25 seconds (see Figure 1) of this ideal value, the trial was considered a success, if not, the lift was discarded. In a given trial, those lifting motions that were found to have occurred during the ±0.25 second window were averaged to create the dependent variables describing the trunk kinematics. The same ±0.25 second time interval was also used in the EMG data processing collected from static holding tasks. Data points within ±0.25 seconds of the time of the designated peak or trough were processed as described below.

The unprocessed EMG data were band-pass filtered at a low-pass frequency of 500 Hz and a high-pass frequency of 10 Hz. A notch filter was also applied that eliminated 60 Hz and its aliases and then these filtered signals were full-wave-rectified. The EMG signals from the MVC trials were reduced to 1/8th second windows and the maximum of these 1/8th second windows was the value used as the denominator in order to normalize the EMG data from the experimental trials. The EMG data collected in the ±0.25 second window were averaged and were used as the numerator for the calculation of the average normalized EMG.

Data Analysis

All statistical analyses in this study were conducted using Minitab 15. Prior to formal statistical analysis, the assumptions of the ANOVA procedure (normality of residuals assumption, non-correlation of residuals (i.e. independence) assumption, and constant variance of residuals assumption) were tested (Montgomery 2005, pp.76-79). Dependent variables that violated one or more assumption were transformed so that the ANOVA assumptions were no longer violated (Montgomery 2005, p.80). Multivariate analyses of variance (MANOVAs) were then conducted on all response measures to control the experiment-wise error rate. Only those independent variables found to be significant in the MANOVA were pursued further in the univariate ANOVA. Tukey-Kramer post-hoc tests were then performed on the significant main effects to further explore the nature of these significant effects. A criteria p-value of 0.05 was used in all statistical tests.

RESULTS

EMG results from load holding task showed that both MASS and CONDITION had a significant effect on muscle activities, but the interaction effect was not significant (Table 1). Post hoc test showed that higher levels of load mass generated higher muscle activity in all muscles groups, however the effect of CONDITION followed different trends for different muscles. From Figure 2 it can be observed that for the erector spinae muscle group, the left and right muscle showed different trends as a function of condition. While the vertical acceleration (and thereby the net sagittal plane moment for both muscles) changed at a constant rate in going' from Condition A to Condition E the changes in the slant angle of the deck surface altered which of the erector spinae muscle would be considered the contralateral and ipsilateral muscle group. The result that these responses are not mirror images of each other indicates that there is an interaction between the magnitude of the vertical acceleration and the deck surface slant angle. In terms of the antagonist muscle groups, the RRA and LRA did not show any clear pattern among different conditions with relatively low activation levels. The external oblique muscles, however, showed a more consistent trend, with significantly higher muscle activity in the moving conditions (A and E) compared with stationary condition C, indicating a trunk stabilization role under these dynamic conditions.

Table 1. MANOVA and ANOVA for normalized EMG.

Independent Variables	MANOVA	ANOVA					
		RES	LES	RRA	LRA	REO	LEO
WEIGHT	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
CONDITION	<0.001	<0.001	<0.001	0.006	0.009	<0.001	<0.001
WEIGHT*CONDITION	0.301	N/A	N/A	N/A	N/A	N/A	N/A

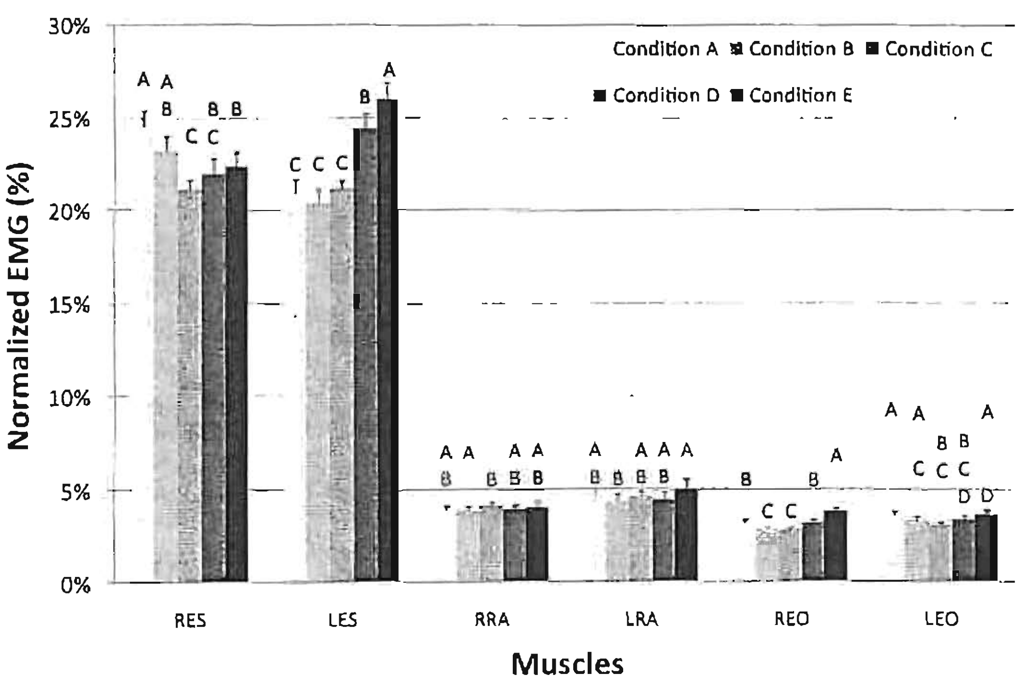


Figure 2: Effect of CONDITION on muscle activity during load holding task. The letters above each column are from the Tukey-Kramer post hoc test. Different letters represent muscle activity levels that are statistically different from one another.

The MANOVA and ANOVA results of trunk kinematics variables data from load lifting and lowering tasks are shown in Table 2. Consistent with the EMG results, trunk kinematics data revealed significant effect of MASS and CONDITION, while their interaction was not significant. The maximum sagittal acceleration during the lifting task and the maximum sagittal deceleration in the lowering task were significantly decreased with the increased load mass. CONDITION also had a significant effect on both acceleration and deceleration. As shown in Figure 3, maximum lifting sagittal acceleration in Condition A (when the load would feel lightest) was significantly higher than Conditions C, D and E. Figure 4 shows that maximum sagittal deceleration (eccentric) during the lowering task followed a different trend as compared to the response during concentric acceleration. In conditions A and E (-0.54 m/s^2 and 0.54 m/s^2) subjects had similar deceleration values and they were significantly higher than the stationary condition C.

Table 2. MANOVA and ANOVA for trunk kinematics

Independent Variables	MANOVA	ANOVA			
		Lifting Sagittal Ang	Lifting Sagittal Acc	Lowering Sagittal Ang	Lowering Sagittal Dec
WEIGHT	<0.001	0.469	<0.001	0.033	<0.001
CONDITION	<0.001	0.950	0.001	0.895	<0.001
WEIGHT*CONDITION	0.884	N/A	N/A	N/A	N/A

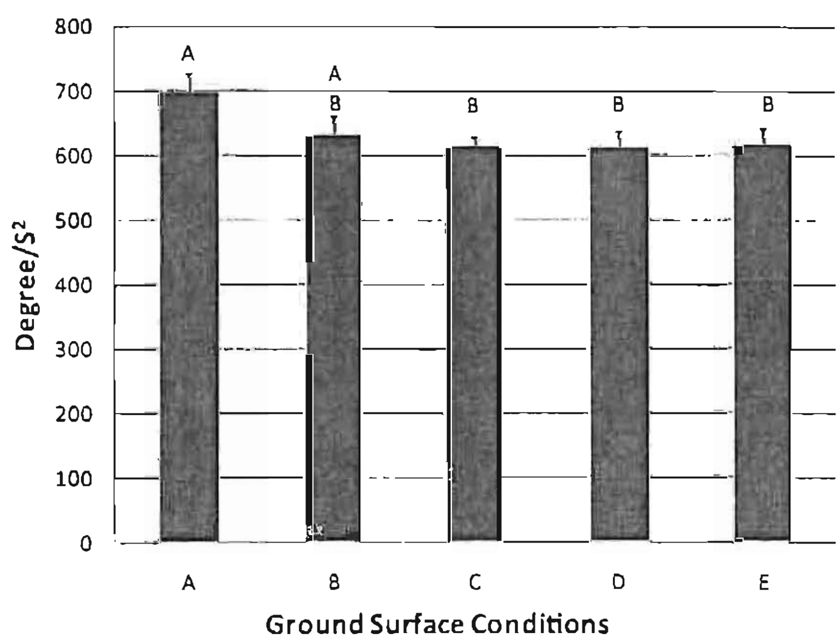


Figure 3: Effect of CONDITION on maximum sagittal acceleration during load lifting task. The letters above each column are from the Tukey-Kramer post hoc test. Different letters represent accelerations that are statistically different from one another.

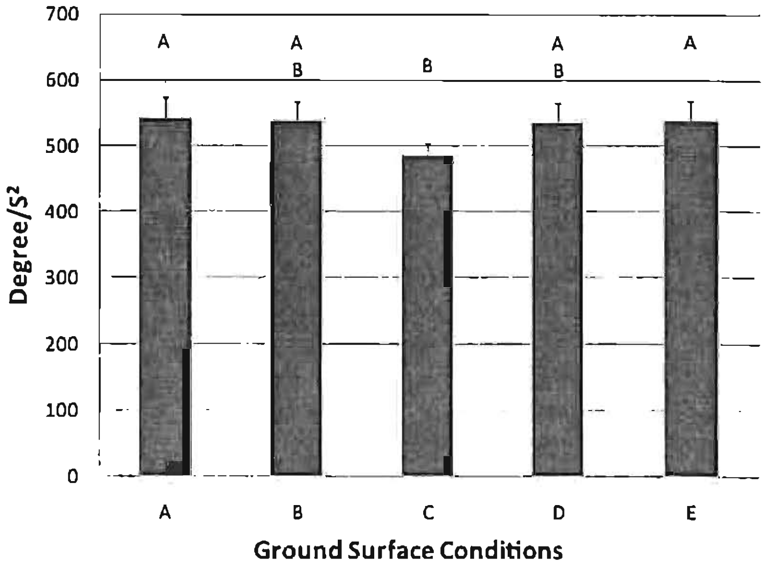


Figure 4: Effect of CONDITION on maximum sagittal deceleration during load lowering task. The letters above each column are from the Tukey-Kramer post hoc test. Different letters represent decelerations that are statistically different from one another.

DISCUSSION

The activity levels of the bilateral erector spinae muscles followed unexpected trends that were the result of a complex interaction between the ground surface slant angle and the vertical acceleration. This created a situation where the role of contralateral and ipsilateral muscles was constantly changing. If one were to view a snapshot of this weight-holding task it would appear to be a sagittally symmetric task. However, the combination of the angular displacement at the feet and the vertical acceleration of the load and the trunk mass create medio-laterally directed forces that essentially change this to an asymmetric lifting task thereby creating the need for contra and ipsilateral muscle forces. Jiang et al. (2005) reported a significant increase of erector spinae muscle activity at 20° and 30° slanted ground angle (but not 10°) and the contralateral muscle activity increased at a greater rate as compared to the ipsilateral muscle. In the current study, although the ground angle was much smaller (0°, 3° and 6°) the significant effect of CONDITION would indicate that effect of slanted ground angle was magnified by the participants in order to maintain stability under the dynamic lifting conditions.

From the profile of RES and LES in Figure 2, the effect of both angular displacement and vertical acceleration can be clearly observed. In the stationary condition (Condition C), both RES and LES had very similar levels of muscle activity (21.1% and 21.2% respectively). Neglecting the effects of the dynamics (i.e. simply considering the changes in the slope of the deck surface) we would expect to see a mirror image response of these two muscles as a function of slant angle (RES muscle activity in Condition A would have the same muscle activation level with LES in Condition E, etc.) Therefore, the average of the two contralateral muscles (and ipsilateral muscles) in these mirror image conditions can be found and we describe this as "ideal" (Figure 5) and suggest that this is the pure effect of the slant angle of the deck surface. From Figure 5 the effect of acceleration on erector spinae muscle activity can be identified as the muscle activity difference between RES, LES and the "ideal" bars. Comparing the "ideal" situation for the contralateral muscle under conditions A and B (-0.54m/s^2 and -0.27m/s^2 ground acceleration) reduced low back muscular activity by 3.0% and 2.7% respectively. When working as ipsilateral muscle the same acceleration reduced 3.7% and 3.3% of muscle activity.

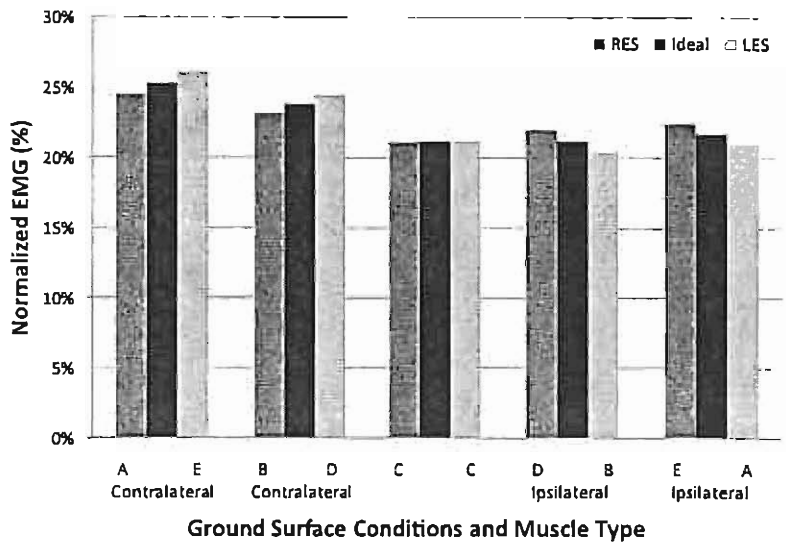


Figure 5: Effect of CONDITION and muscle working type on the erector spinae muscle activity.

Under the variable dynamic lifting conditions of this experiment, one would have expected significant effects of the magnitude of the acceleration and slant angle of deck surface on the levels of antagonist co-contraction. The results showed that the rectus abdominis muscles were largely unaffected by these changes, but the external oblique muscles followed a much more consistent trend indicating an important role in system stabilization. The significant medio-lateral component of the line of action of the external obliques would provide the necessary stabilization forces to counter the side to side forces as implied by the contralateral-ipsilateral shifting as observed in the erector spinae. The relatively simple, static exertions performed in this experiment might underestimate the level of external oblique muscle activity that would be required under more realistic, dynamic lifting motions performed on a fishing boat.

Kinematics data revealed that both MASS and CONDITION had significant effect on the maximum sagittal acceleration during lifting task, lighter mass caused higher sagittal acceleration rate. The effect of CONDITION could also be related to changes in the *effective* weight of the load. In Condition A, the -0.54m/s^2 vertical acceleration makes the load about 5% lighter than the static condition (Condition C) and 10% lighter that than Condition E. As expected, this "lighter" load generated the highest peak sagittal angular acceleration during the concentric lifting motion, but the opposite was not true – the peak sagittal angular acceleration in Condition E was not significantly lower than Conditions B, C or D. The results of this study confirm the concern of Kingma et al. (2003) that their simulation may make simplifying assumption that could be false. The magnitude of the ground accelerations (and the accompanying angular displacements) in the current study did generate changes in the peak sagittal plane angular acceleration and decelerations used by the participants, but did not impact the sagittal plane range of motion.

In previous related studies researchers investigated the effects of sea motion on relatively large vessels where periods of motion are relatively longer than those experienced in smaller fishing boats. In Matthews et al. (2007) for example, the ship motion simulator employed in this study simulated a coast guard supply vessel experiencing 7 meter waves with 5-10 second wave period. Comparison of the results of this previous study with the current study is somewhat difficult for these reasons, but also because the current study placed fairly stringent controls on the magnitude of the instantaneous deck surface angle and vertical acceleration. In the Matthews (2007) study, the boat simulator moved with a 5-10 second period and the subjects lifted at a rate of six lifts per minute but the timing of the individual lifts was not controlled relative to the boat motions so the instantaneous angle and acceleration of the deck surface were not controlled and reported. The Matthews et al. (2007) approach may provide a more realistic view of lifting activities on a boat where the timing of the lifts is generally not controlled, but it also increases the variability in the biomechanical responses. The current study controlled the timing of the lifts relative to the boat motions so that the effects of specific levels of deck motion characteristics could be related directly to the resulting biomechanics responses.

There are several limitations to the current work should also be noted. First, the current study was conducted on an experimental set up that simulated a sinusoidal motion of a small fishing boat. Realistic motions of a small fishing boat are generally not purely sinusoidal. Also, the physical dimensions of the BMS in this study provided only one natural motion period (~1.6s). For safety reasons the amplitude of angular displacement of the ground motion never went beyond 6^0 which represents only moderate sea conditions, more severe motions may provide interesting changes in the trunk muscle coactivation patterns. Second, the participants in this study were college aged students with limited experience working on fishing boats. The responses of seasoned fishermen that have their "sea legs" would provide an interesting contrast for our results. Third, the current study only considered the vertical acceleration and coronal plane angular displacement during rolling motion, future research needs to be done to evaluate the effect of other type of ground motions (e.g. pitch and quartering). Finally, a laboratory study can provide good control of all independent variables and precise measurement of dependent measures, but a field study conducted on smaller fishing boat would provide valuable verification of the results of this study.

CONCLUSIONS

The purpose of this study was to investigate the effect of ground surface motion on kinetics and kinematics during manual material handling tasks. Normalized EMG results clearly showed the impact of both ground angular displacement and vertical linear acceleration on the trunk muscles. With a relatively small range of angular displacement used in this study, the erector spinae muscles experienced higher muscle activity when working as a contralateral muscle and this contralateral designation changed as a function of ground surface slant angle. External oblique muscle activity increased with the increasing ground motion indicating their role as an important stabilizer during this dynamic activity. Kinematics data showed that there were changes in the lifting strategy with greater angular acceleration under conditions where the vertical acceleration of the ground surface made the load feel lighter than under the other motion conditions.

REFERENCES

Conway, G.A., Lincoln, J. M., Hudson, D. S., Bensyl, D. M., Husberg, B. J., Manwaring, J. C., 2002. Surveillance and Prevention of Occupational Injuries in Alaska: A Decade of Progress, 1990–1999. Cincinnati, Ohio: Alaska Field Station, Division of Safety Research, NIOSH.

Driscol, T., Ansari, G., Harrison, J., Frommer, M., Ruck, E., 1994. Traumatic work related fatalities in commercial fishermen in Australia. Occupational and Environmental Medicine 51, 612–616.

Faber, G. S., Kingma, I., Delleman, N. J., Van Dieën, J. H., 2008. Effect of ship motion on spinal loading during manual lifting. Ergonomics 51(9), 1426 –1440.

Holmes, M.W., MacKinnon, S.N., Matthews, J., Albert, W.J., Mills, S., 2008. Manual materials handling in simulated motion environments. Journal of Applied Biomechanics 24(2), 103-111.

Jensen, O., 2000. Non-fatal occupational fall and slip injuries among commercial fishermen analyzed by use of the NOMESCO Injury Registration System. American Journal of Industrial Medicine 37,637–644.

Jiang, Z., Shin, G., Freeman, J., Reid, S., Mirka, G. A., 2005. A study of lifting tasks performed on laterally slanted ground surfaces, Ergonomics 48(7), 782 –795.

Kingma, I., Delleman, N.J., Van Dieën, J.H., 2003. The effect of ship accelerations on three-dimensional low back loading during lifting and pulling activities. International Journal of Industrial Ergonomics 32, 51–63.

Kucera, K.L., Mirka, G.A., Loomis, D., Marshall, S.W., Lipscomb, H.J., Daniels, J., 2008. Evaluating Ergonomic Stresses in North Carolina Commercial Crab Pot and Gill Net Fishermen. Journal of Occupational and Environmental Hygiene 5:3, 182 – 196.

Lipscomb, H., Loomis, D., MacDonald, M., Kucera, K., Marshall, S., Leiming, L., 2004. Musculoskeletal symptoms among commercial fishers in North Carolina. Applied Ergonomics 35, 417–426.

Marras, W.S., Fathallah, F.A., Miller, R.J., Davis, S.W., and Mirka, G.A., 1992. Accuracy of a Three-Dimensional Lumbar Motion Monitor for Recording Dynamic Trunk Motion Characteristics. International Journal of Industrial Ergonomics 9, 75-87.

Matthews, J.D., MacKinnon, S.N., Albert, W.J., Holmes, M., Patterson, A., 2007. Effects of moving environments on the physical demands of heavy materials handling operators. International Journal of Industrial Ergonomics 37, 43–50.

Mirka, G.A. and Marras, W.S., 1993. A stochastic model of trunk muscle coactivation during trunk bending. Spine 18, 1396-1409.

Montgomery, D.C., 2005. Design and analysis of experiments. 6th ed. New York: John Wiley & Sons.

Norrish, A., Cryer, P., 1990. Work related injury in New Zealand commercial fishermen. British Journal of Industrial Medicine 47, 726–732.

Roberts, S.E., 2004. Occupational mortality in British commercial fishing, 1976–95. Occupational and Environmental Medicine 61(1), 16–23.

Thomas, T. K., Lincoln, J. M., Husberg, B. J., Conway, G. A., 2001. Is it safe on deck? Fatal and non-fatal workplace injuries among Alaskan commercial fishermen. American Journal of Industrial Medicine 40(6), 693–702.

Torner, M., Blide, G., Eriksson, H., Kadefors, R., Karlsson, R., Petersen, I., 1988. Musculo-skeletal symptoms as related to working conditions among Swedish professional fishermen. Applied Ergonomics 19(3), 191–201.

Torner, M., Almstrom, C., Kadefors, R., Karlsson, R., 1994. Working on a moving surface-a biomechanical analysis of musculoskeletal load due to ship motions in combination with work. Ergonomics 37, 345-362.

Trujillo, A. P., Thurman, H. V., 2008. Essentials of Oceanography, 9th ed. Upper Saddle River, NJ: Pearson Education.

Wertheim, A.H., 1998. Working in a moving environment. Ergonomics 41 (12), 1845–1858.

Wertheim, A.H., Kemper, H.C., Heus, R., 2002. Maximal oxygen uptake during cycling is reduced in moving environments; consequences for motion-induced fatigue. Ergonomics 45 (3), 186–202.

SPECIFIC AIMS #3 & #4: DESIGN AND EVALUATE ERGONOMIC CONTROLS

AIMS #3&4; PAPER #1

TITLE: **Ergonomic Interventions for Commercial Crab Fishermen**

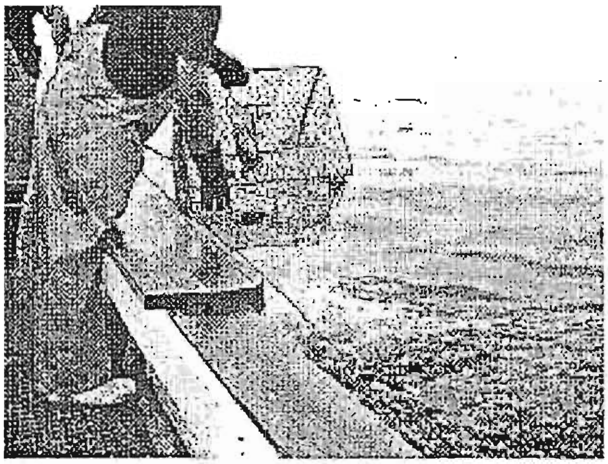
ABSTRACT

Work tasks in the commercial fishing industry require strength, endurance and coordination and expose fishermen to many of the recognized risk factors for the development of work-related musculoskeletal disorders. The focus of the current study was the design, development and testing of ergonomic interventions to reduce exposure to these risk factors. In a laboratory study of these interventions, EMG and motion analysis systems were used to quantify changes in muscle force and body postures. The results of laboratory evaluations showed significant reductions in muscle force requirements and awkward postures with these interventions, demonstrating the effectiveness of the interventions. Field evaluations of these interventions provided a more subjective "usability" evaluation of the interventions more focused on efficacy aspects of the interventions.

INTRODUCTION

The commercial fishing industry is vital to the economy of many coastal communities in the United States. In North Carolina alone there are about 7000 commercial fishermen with endorsement to sell licenses and the number of individuals actively engaged in fishing activities is significantly larger because commercial licenses are not required for crewmembers on fishing vessels or for those individuals that perform other support activities for the fishermen (estimates from the North Carolina Division of Marine Fisheries). The main types of fishing methods used in the North Carolina estuaries include gillnetting, crab-pot fishing and trawling. These will be the focus of the proposed work.

Commercial fishermen work long hours in a dynamic natural environment that includes excessive heat, frigid cold, high winds, precipitation of all sorts, and a wet, moving standing worksurface that creates unusual, three-dimensional forces and inertial effects (Figure 1). The physical demands of the work tasks require strength and endurance as well as high levels of coordination due the dynamic standing surface. These characteristics expose to workers to many of the recognized risk factors for the development of work-related musculoskeletal disorders. These risk factors include repetitive bending and lifting, static/awkward postures, high force lifting exertions, repetitive motion and exertions of the upper extremity (including the shoulder and elbow and hand/wrist), exposure whole body vibration, slip and fall risks and high levels of muscular fatigue.



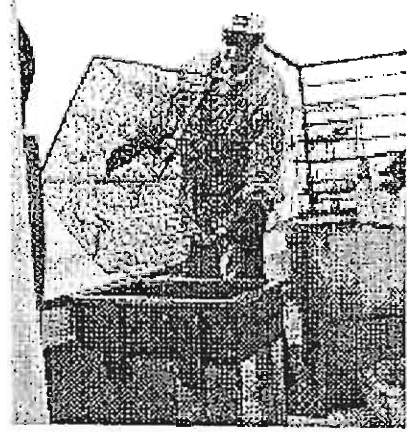


Figure 1: Sample manual material handling requirements during commercial crab fishing (lifting crab pot from water, shaking crabs out of crab pot.).

From the perspective of the epidemiology of musculoskeletal disorders in commercial fishermen, there have been a few studies that have attempted to quantify the impact of these disorders on this population. A study by Moore (1969) showed that sprains and strains were ranked fourth in terms of duration of incapacity after dislocation and fractures, contusions, infected traumas. More recently, in a study of New Zealand insurance data, Norrish and Cryer (1990) found that material handling (lifting, lowering, loading and unloading boxes) were responsible for approximately one-third of the injuries and one-third of the costs of work-related musculoskeletal disorders in this group of commercial deep sea fishermen. As they investigated this data more closely, they found that two-thirds of all musculoskeletal injuries were described as strains of the muscles of the back. In 1996, Jensen (1996) found that 10 percent of injuries in a Danish fisherman cohort were sprains and strains and of these, 10 percent were strains of the back. Torner and colleagues (Torner et al 1988a,1998b, 1990, 1991, 1994, 1995, 1999a, 1999b Peterson et al, 1989) have performed a number of studies considering Swedish deep sea fishermen. Seventy-four percent of the fishermen sampled in one study reported some type of musculoskeletal symptoms in the last 12 months (Torner et al., 1988). These authors also were reported that motion of the boat and increase the stress on the musculoskeletal system particularly the low back and lower extremity (Torner et al., 1994; and Peterson et al., 1989).

More recently Lipscomb et al. (2002) showed a very high prevalence rate for musculoskeletal symptoms. In this study they showed that, of the fishermen studied, 52% had symptoms in the low back, 41% had symptoms in the hand/wrist, 27% had symptoms in the elbow and forearm, and 25% had symptoms in the shoulders. To begin to develop an appreciation for the real cost associated with these symptoms, they further showed that 38% of the fishermen reported that these symptoms were at a level sufficient to limit their level of work activity in the last year. These statistics emphasize the significance of the problems faced in this industry, but also highlight the opportunities for improvement through the development of effective ergonomic interventions.

Engineering controls are generally recognized as the most effective way to reduce the incidence and severity of work-related musculoskeletal disorders. Over the past decade there has been an increase in the number of ergonomic intervention studies published that have evaluated the effectiveness of engineering controls (Aaras, 1994; Algera, 1990; Burton et al, 1997; Farmilo, 1995; Garg and Owen, 1992; Goldenbar and Schulte, 1994,1996; Kemmlert, 1996; Lavender and Marras, 1990; Moore, 1994; Orgel et al, 1992; Osorio et al, 1994; Rubenowitz, 1997; Welch et al, 1995; Westgaard and Winkel, 1996,1997; Westlander et al, 1995). Generally, the researchers performing these intervention studies will observe a job and then develop engineering redesigns of the activities of these jobs and document a reduction in the biomechanical stress experienced by the worker. In their review of intervention research methods, Westgaard and Winkel (1997) point out four different issues that relate to the validity an intervention study: 1) statistical conclusion validity, 2) internal validity, 3) construct validity, and 4) external validity. Statistical conclusion validity refers to the appropriateness of the study design, including issues of sample size, control group selection, interrelationships between outcome variables, and appropriate statistical analysis tests. Internal validity refers to the potential for the development of a causal relationship, and is affected by the choice of a control group and effective placebo for that control group. Construct validity refers to the choice of the dependent measures and how well they reflect the true underlying construct that they are designed to represent. Control group choice again plays a very important role in the interpretation of construct validity. Finally, external validity refers to the ability to find similar results in different settings. The main issue in this realm is to conduct the study in a realistic setting so that, as in the case of a laboratory-based study, there is no loss of confidence in the results as they are translated to the more complex workplace.

A review of the current archival literature found very little research that focused on the development and testing of ergonomic interventions for the commercial fishing industry. In their work investigating the ergonomic exposures of fishermen on Massachusetts fishing vessels, Fulmer and Buchholz (2002) used the PATH ergonomic assessment technique to quantify the postures and work activities of fishermen involved in gillnetting, otter trawling and lobstering. They were able to identify a number of work factors (production speed, materials handling, etc.) that had an impact on the exposure to risk factors for these workers. They conclude their discussion with a list of potential ergonomic interventions that could be developed in an attempt to address these risk factors but, to date, nothing has appeared in the literature that quantitatively illustrates the impact of these or any other ergonomic interventions for commercial fishermen. The focus of the current study was the development and evaluation of ergonomics interventions designed to reduce exposure to recognized risk factors for the development of musculoskeletal disorders in the commercial crab fishing industry.

METHODS

As an introduction to the methods employed in this study, we provide an overview of the sequence of tasks performed in a typical cycle of the operation of crab pot fishing. First the captain of the boat drives up to a buoy floating in the water and reaches out with a long pole with a hook on the end (often called a catch stick and is usually between 4 and 8 feet long and is made of aluminum or wood) and hooks the rope attached to the buoy. The captain then pulls this pole in and feeds the rope into a mechanized device called a pot-puller which is then activated and draws the crab pot up from its resting place on the bottom of the ocean or river. After feeding the pot-puller, the captain then sets down the catch stick and drives to the next buoy. Once the pot-puller lifts the pot to the side of the boat, the mate (second man on the team) lifts the pot from outside of the boat at about mid shin level to the interior of the boat. As the mate is lifting the pot into the boat he takes the bait from inside the crab pot and throws it away. Once the pot is in the boat the mate shakes the crab pot vigorously to get the crabs to release their grip in the wire structure of the crab pot and empties them into the crab box. Once all of the crabs are out, the mate puts a new frozen bait fish in the crab pot and throws the baited crab pot back overboard. The mate then bends over the crab box and sorts through everything that was dumped into the box. The sorting of the crabs is done to throw back those that are too small and to identify those that are in the soft shell stage. In addition, other kinds of sea wildlife find their way into the crab pots and these are also sorted and returned to the water. At just about the time the mate has finished with the sorting operation a new crab pot rope has been inserted into the puller and new pot is on its way up to the side of the boat. The cycle time between pots is about 60 seconds (typical for a two man crew) and depending on the number of pots in the water, these fishermen can work from between 4 to 10 hours per day.

Apparatus for Laboratory Studies

A simulated boat (4' wide x 12' long x 39" high sides) was developed to provide a functional working environment for subjects performing experimental tasks. Surface electromyography (EMG) (Delsys, Inc, Boston, MA, USA) and the lumbar motion monitor (LMM) were used to capture the muscle activation and trunk kinematic data, respectively. Eight bi-polar surface electrodes were placed on the skin of subject over the right erector spinae (RES), left erector spinae (LES), right rectus abdominis (RAB), left rectus abdominis (LAB), right anterior deltoid (RAD), left anterior deltoid (LAD), right posterior deltoid (RPD), left posterior deltoid (LPD). Electromyography and LMM data were both collected for 10 seconds for each trial with frequency of 1024 Hz and 60 Hz, respectively. To capture the extreme postures seen during the crab sorting task, a digital camera aligned perpendicular to the sagittal plane captured overall trunk flexion.

Data Processing and Statistical Analysis

EMG data were filtered (high pass 15 Hz, low pass 500Hz and notch filtered at 60Hz to remove noise artifacts) and then the data within the work task window were averaged and then normalized with respect to the MVC EMG in for each muscle (MVC exertion was partitioned into $1/8^{th}$ second windows and the EMG data in these windows were averaged and the maximum of these was identified as the MVC level for that muscle). The average EMG data reflects the average of all EMG data occurring during the work task, while the values described as "peak" are the largest of the $1/8^{th}$ second windows occurring during the work task. Trunk kinematic data from the LMM were captured and the maximum, minimum and average angle, velocity and acceleration in the sagittal, coronal and transverse planes were found. Student's t-test with each subject as a block was used to test the significance of muscle activity differences. JMP 6.0 program (JMP Statistical Discovery 6.0.0, SAS Institute Inc., Cary, NC, USA) was used to carry out all the statistical analyses.

Participants

Laboratory Studies. Seven participants were recruited from the university student population. Subjects were all free from any low back or other musculoskeletal problems and they provided written informed consent prior to participation (approved by the Institutional Review Board of Iowa State University).

Field Study. Three commercial crab fishermen were interviewed and provided subjective feedback on the ergonomic interventions presented. Not all fishermen used each of the devices. Each provided written informed consent prior to participation.

Experimental Procedure

When the subject arrived to the lab, a brief introduction about the experiment was provided. Written informed consent was obtained before participation. After a short warm up exercise, eight bi-polar surface electrodes were secured on the skin over the muscles. Maximum voluntary contractions of each of the eight muscles were generated against static resistance provided by an isokinetic dynamometer. The subject then put on the LMM and was led onto the boat and performed the fishing tasks.

The Design and Evaluation of Ergonomic Controls

In the following sections each of these tasks will be described, a brief summary of the results of Specific Aims 2&3 is provided to show the motivation for investing time in these tasks, and then the intervention and the results of the laboratory and field testing of the intervention (where appropriate and conducted) will be presented.

The Tasks and the Interventions

The tasks for intervention (and the interventions) evaluated in this research were:

1) **Hook Buoy** - a revised work method (hand-over-hand) to hook the buoy and bring it to the side of the boats,
2) **Lift Crab Pot** - a ramp system for bringing the crab pots out of the water to a waist level position on the washboard of the side of the boat,
3) **Shake Crab Pot** - a boom and hook system that supported the weight of the crab pots during the process of shaking the crabs out of the pots into the crab box,
4) **Sort Crabs** - a false-bottom topper for the crab box, and
5) **Wash Pot** - a crab pot washing system.

1. Project #1: Hook Buoy

1.1. Description of Task

In this task the captain

1) drives to a buoy and puts the boat in neutral,
2) picks up the catch stick which is leaning near the steering wheel,
3) reaches the hook out over the side of the boat,
4) hooks the rope attached to the buoy,
5) pulls (typically in one smooth motion) the rope to the pulley of the pot puller,
6) activates the pot puller and
7) sets the hook down and engages the boat engine to get to the next buoy.

1.2. Motivation for Intervention

Review of the injury data and interviews with fishermen indicated that captains often have shoulder problems, typically of the right shoulder. Observation of the postures made it fairly clear that one contributor to these complaints is the awkward abduction/extension shoulder posture assumed by the captain as the rope is fed into the pulley of the pot puller (Figure 2.)

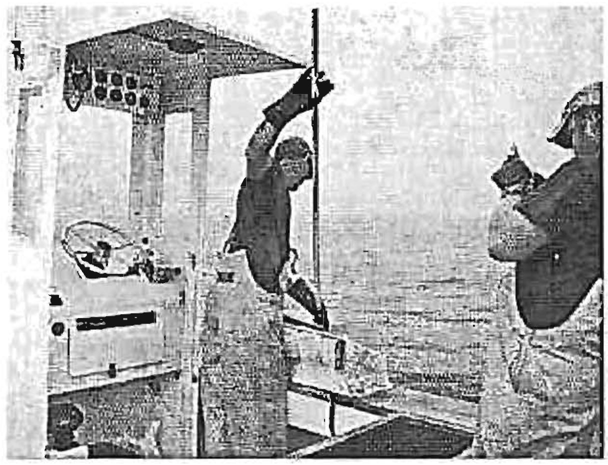


Figure 2. Using the catch stick to feed the rope into the pot puller.

1.3. Ergonomic Intervention

After some consideration and engineering design for a mechanized system for capturing the buoy, we resolved to generate a simple work methods change to this activity. Specifically, we recommend that the captain use a hand-over-hand method to raise the buoy to the pot puller, instead of making one sweeping motion (Figure 3.) From a productivity standpoint, this was found to increase slightly the time to complete the task.

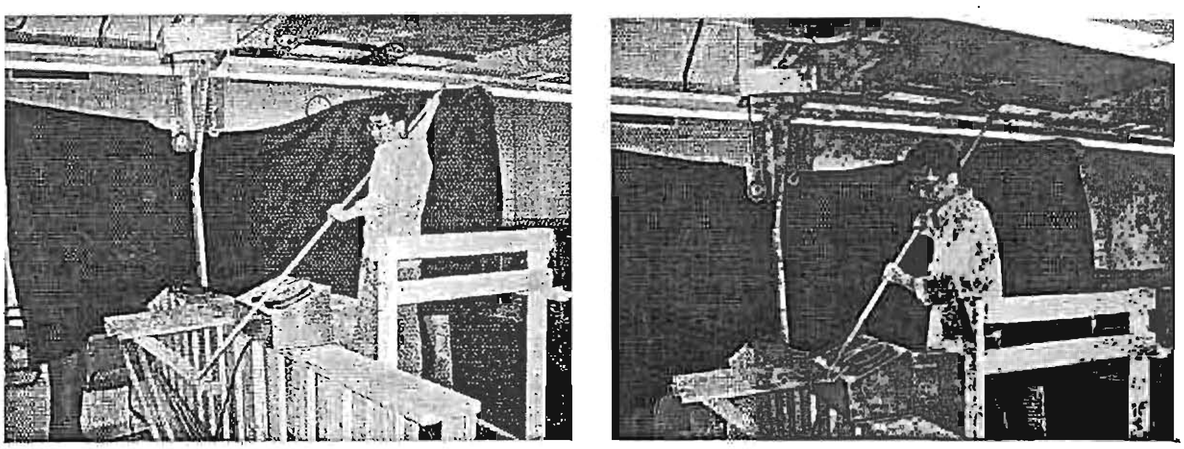


Figure 3. End position of the continuous motion technique (left) and the hand-over-hand technique (right).

1.4. Evaluation of Intervention

Experimental Design

In the study of the hook buoy task one independent variable was considered: technique (one motion or hand- over-hand); and there were eight dependent measures: the peak and average normalized EMG values for each of eight muscles (right and left pairs of the posterior deltoid and the anterior deltoid).

Results

The laboratory evaluation of this change to the technique showed significant reductions in the deltoid muscle activity required to perform the task, both for the peak and average values observed (Table 1 and Figure 4).

Table 1. MANOVA and ANOVA results of for normalized EMG for the hook buoy task.

Independent Variable	EMG	MANOVA	RAD	LAD	RPD	LPD
Intervention (Work Method)	Peak	***	***	*	*	**
	Avg	***	***	**	***	***

*p < 0.05, **p < 0.01, ***p < 0.001

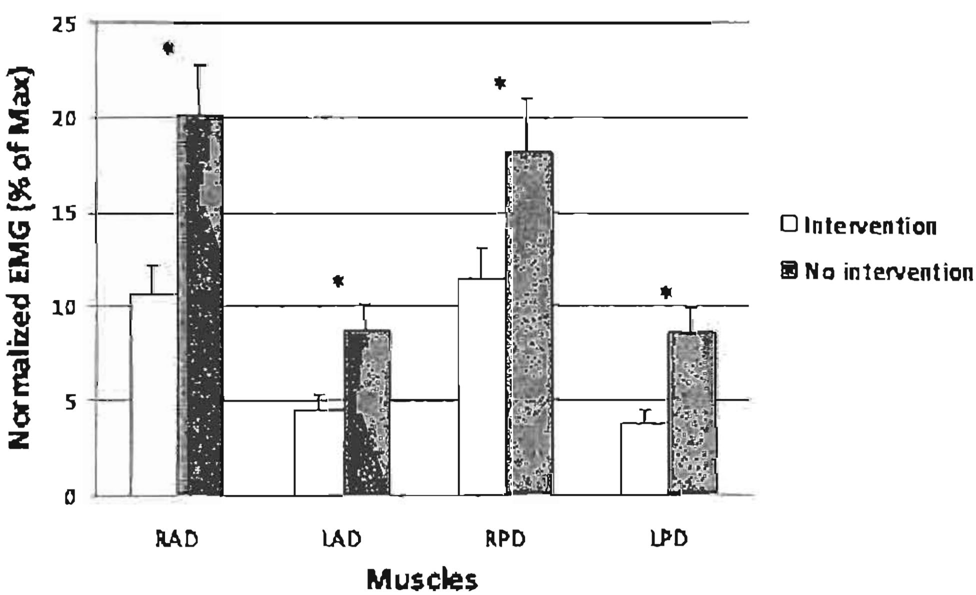


Figure 4. Effect of Intervention on peak deltoid muscle activities during the Hook Buoy task. Significant effects shown by "*"

2. Task #2: Lift Crab Pot

2.1. Description of Task

In this task the mate

1) reaches over the side of the boat and grasps the crab pot,
2) lifts the crab pot over the side of the boat and discards the old bait, and
3) and unhooks the latch to allow the crabs to be shaken out in the next task.

2.2. Motivation for Intervention

Review of the injury data and interviews with fishermen indicated that mates have a high prevalence of low back problems and the biomechanical analyses of the tasks performed by these fishermen indicated that this particular task was high risk because of the trunk posture (asymmetric trunk flexion), the repetition rate (one lift per minute) and high force exertions (pots can weigh up to 40 lbs) (Figure 5.)

Figure 5. Lifting the crab pot.

2.3. Ergonomic Intervention

After several iterations of engineering design and prototyping the research team settled on a ramp mechanism that used the pulling force of the pot puller to run the crab pots up a PVC ramp system to bring the crab pots up to mid torso level, which eliminated much of the awkward posture of the torso (Figure 6).

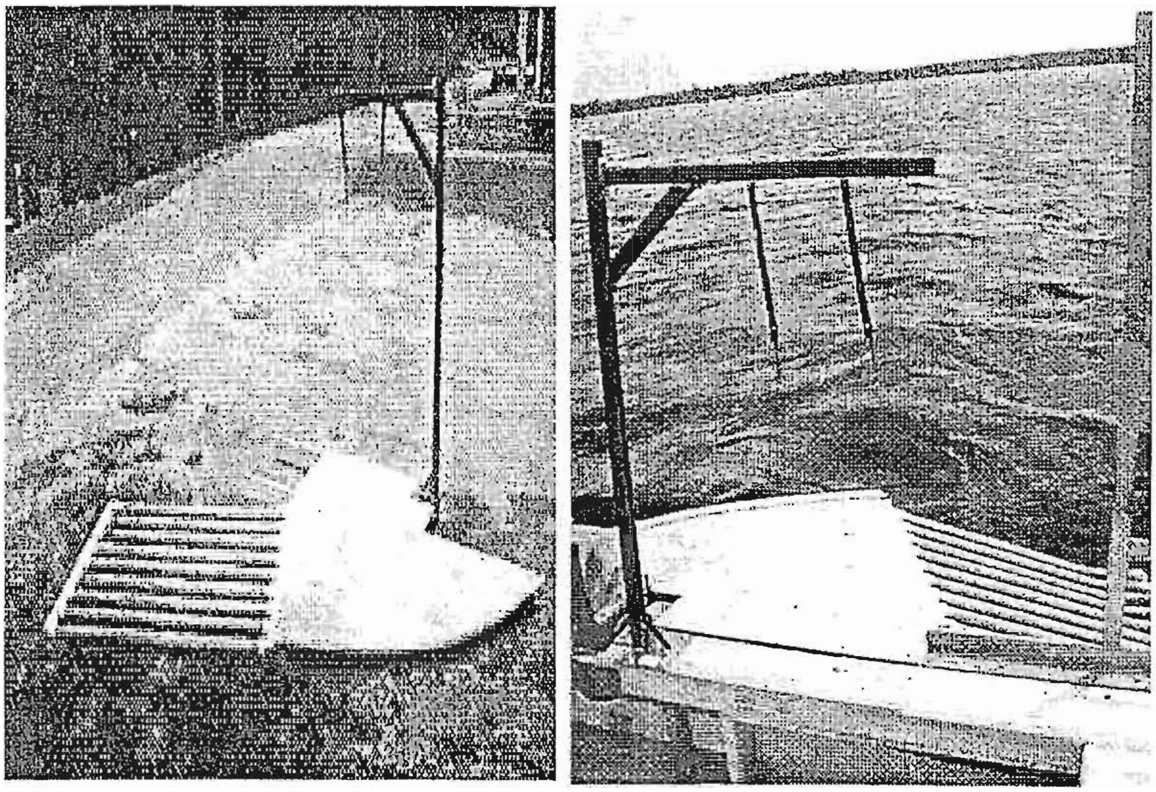


Figure 6. The ergonomic intervention lying on the ground at the dock (left) and mounted on the side of a crab fishing boat (right).

2.4. Evaluation of Intervention

Experimental Design

In the study of the lift crab pot task two independent variables were considered: load weight (20lbs vs. 30lbs) and intervention (intervention or no intervention.) There were 17 dependent variables considered in this task: the average and peak normalized EMG activity of the eight muscles and the maximum sagittal flexion angle. The mock-up of the intervention used in the laboratory testing of this intervention is shown in Figure 7. The location of the crab post simulated the location from which the fishermen would lift the crab pot in both the current and intervention condition.

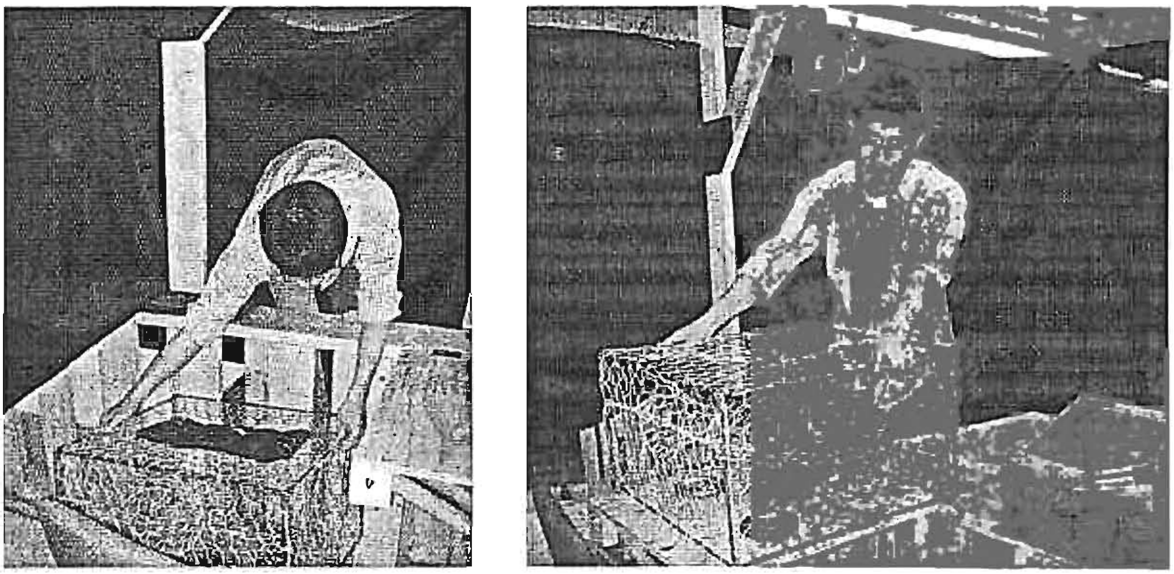


Figure 7. Starting position of the lift crab pot task using the current technique (left) and the intervention technique (right).

Results

The laboratory evaluation of this engineering control showed significant reductions in the activity of all muscles sampled (both average and peak values) (Table 2 and Figures 8 and 9). The interaction between weight and intervention was not significant for any of the muscles activations considered. The intervention had a significant effect on peak sagittal angle (Figure 10.)

Table 2: MANOVA and ANOVA results for normalized EMG for the Lift Crab Pot intervention

Independent Variable	EMG	MANOVA	RES	LES	RRA	LRA	RAD	LAD	RPD	LPD
Intervention	Peak	***	***	***	***	***	***	***	***	***
	Avg	***	***	***	***	***		***	***	***
Load Weight	Peak	***	***	***			**	*	**	*
	Avg	***	***	***			***	*	*	**
Height × Weight	Peak									
	Avg									

**p* < 0.05, ***p* < 0.01, ****p* < 0.001

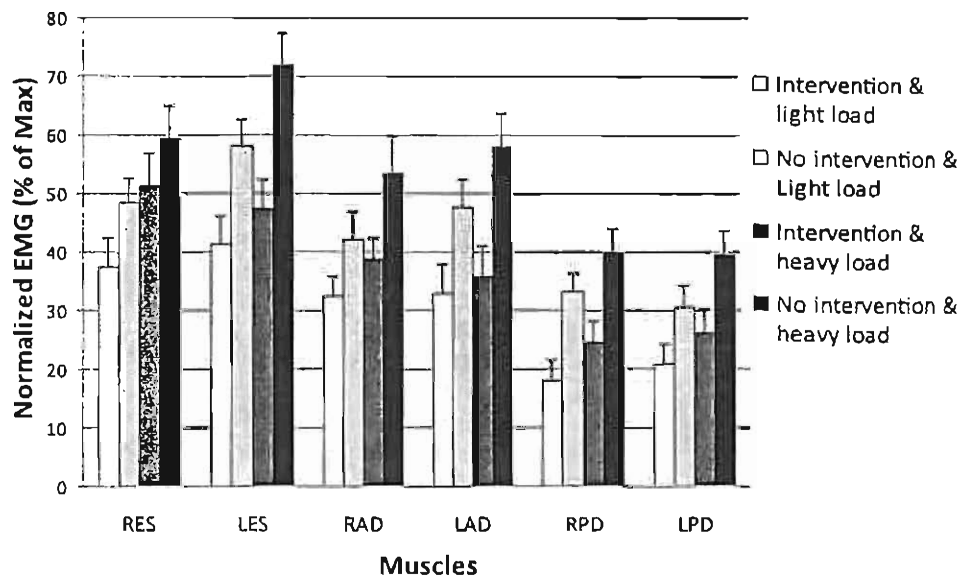


Figure 8. Significant effect of both Intervention and Load Weight on peak muscle activities during the Lift Pot task

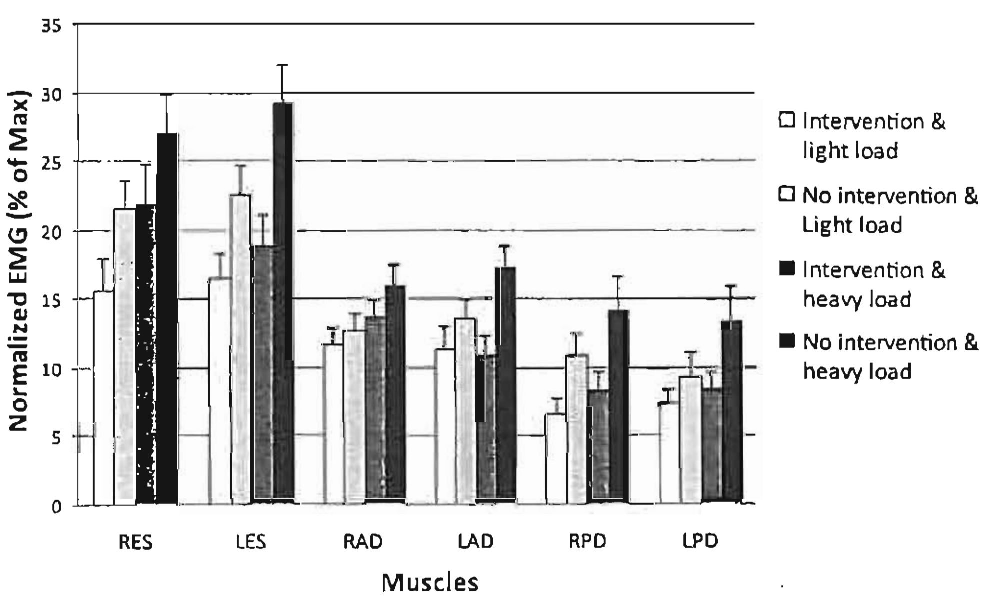


Figure 9. Significant effect of both Intervention and Load Weight on average muscle activities during the Lift Pot task

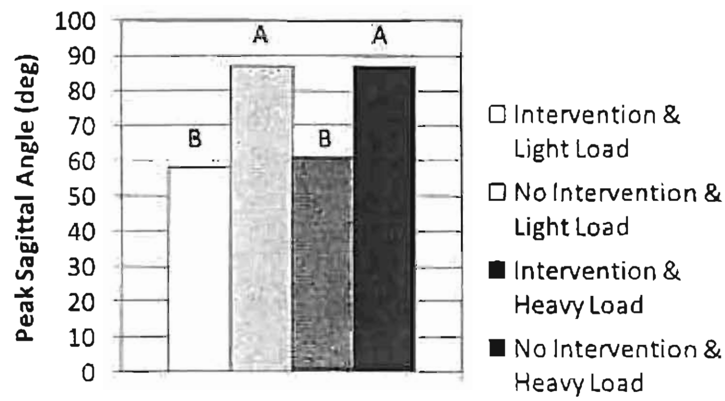


Figure 10. Effect of Intervention and Load Weight on peak sagittal angle during Lift Pot task. Columns with the same letter are not statistically significantly different.

Field evaluation of this intervention required that the fishermen mount the device to the side of the boat and work with this ramp system. The purpose was to evaluate the functionality of the system under realistic conditions and to gather some usability assessment of the device. Figure 11 shows the device as mounted on the side of one crab fisherman's boat. The first figure show the device mounted. The second figure shows the crab pot beginning its run up the PVC pipe ramp. The third figure shows the crab pot at it final position before being lifted by the fisherman (represents the position simulated in the lab experiment shown in Figure 7 (right hand figure of Figure 7.)

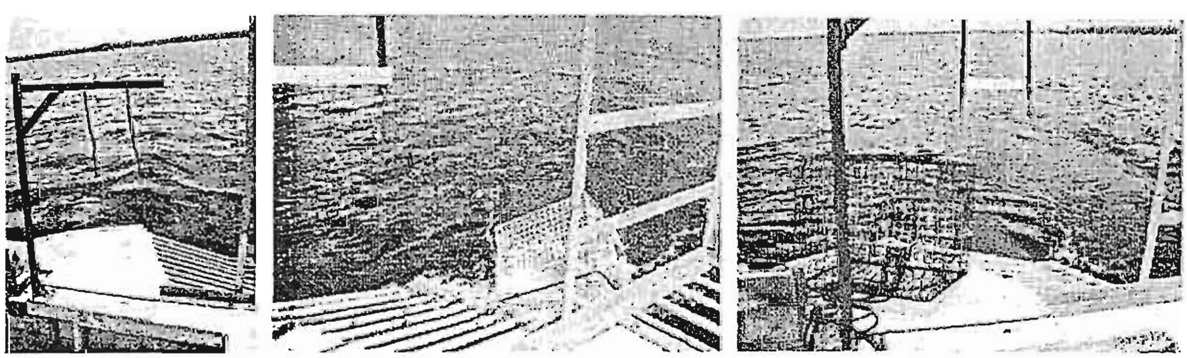


Figure 11. The lift crab intervention used in the field. The ramp system mounted on the side of the boat (left), the crab pot beginning its run up the ramp (middle) and the crab pot at it stopping point (right).

Results

The field evaluation of this intervention received mixed evaluations. In some cases the fishermen felt that the intervention accomplished what it intended to accomplish – reduce stress on the back. Unfortunately, the weather conditions had a great influence on the functionality of the system. Under windy conditions the boat would tend to rotate thereby changing the orientation of the rope of the crab pot relative to the PVC ramp. If it was a two-man crew the captain would be able to reorient the boat during the process and maintain the orientation of the rope with the PVC ramp and the system would work well (~95% effective). If it was a one-man crew and the boat was turning it was quite difficult for the captain to move quickly enough to activate the pot-puller while the boat was still in the correct orientation (only about 25% effective.) This was particularly important because of the fishermen consulted all thought that the intervention would be particularly effective for older fishermen that often work by themselves. It was also noted that this particular intervention would be of greatest value for those fishermen that conduct straight line crab fishing and less so for those that tend to circle around the crab pot during fishing.

The end result of these field research consultations was that the device 1) achieves its biomechanical goals and 2) could be modified with a more 180° orientation of the PVC pipes to allow for a broader utility in the one-man crabbing operations and varied fishing conditions/ techniques.

3. Task #3: Shake Crab Pot

3.1. Description of Task

In this task the fisherman

1) Lifts the crab pot into the boat (where lift crab pot ended),
2) Takes the bait fish out of the trap,
3) Holds the crab pot over the crab box,
4) shakes the crabs out of the pot into the crab box,
5) re-baits the pot, and
6) tosses the pot back into the water.

3.2. Motivation for Intervention

Review of the injury data and interviews with fishermen indicated that mates have a high prevalence of shoulder and low back problems and the biomechanical analyses of the tasks performed by these fishermen indicated that this particular task was high risk for shoulder injury because of the repetitive shoulder movements and high shoulder moments when vigorously shaking these pots (weighing up to 40 lbs) (Figure 12.)

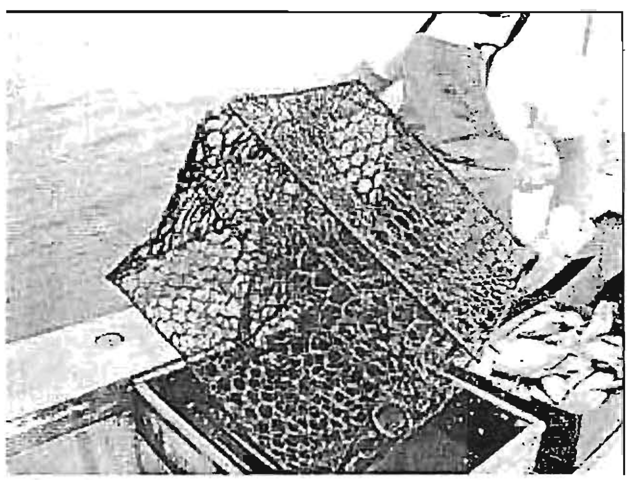


Figure 12. Shaking the crab pot.

3.3. Ergonomic Intervention

The typical procedure is for the fisherman to lift the pot and shake the crabs out. In the intervention condition the pot is held by a hook and the fisherman shakes the pot from side to side allowing the hook to support most of the crab pot weight (Figure 13.) In the laboratory testing of the hook system a simple single chain device (Figure 14) was used to support the mass of the crab pot, however, during the field testing a modified, dual-hook system was put in place to provide a more stable system to support the pots (Figure 13).

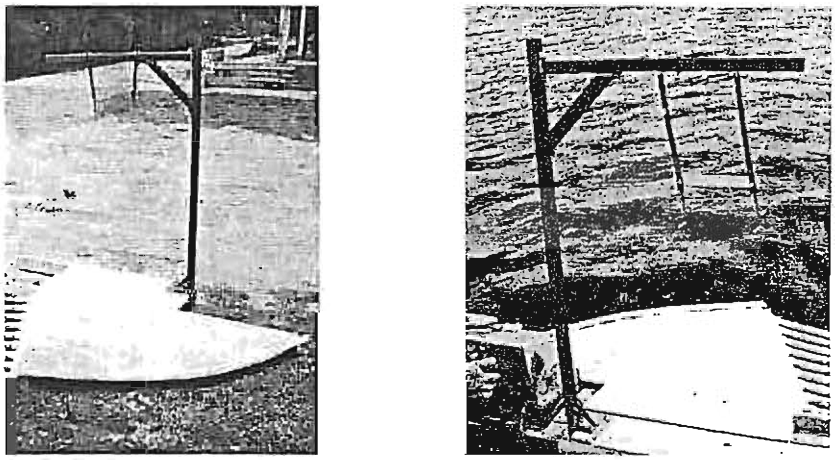


Figure 13. The ergonomic intervention lying on the ground at the dock (left) and mounted on the side of a crab fishing boat (right) with the ramp system attached.

3.4. Evaluation of Intervention

Experimental Design

In the shake crab pot task one independent variable was considered: intervention (intervention or no intervention.) There were 16 dependent variables considered in this task: the average and peak normalized EMG activity of the eight muscles. The mock-up of the intervention used in the laboratory testing of this intervention is shown in Figure 14. In the no-intervention condition, the subjects supported the weight of the crab pot while the shaking the pot for a period of ten seconds (left frame of Figure 14.) In the intervention condition the weight of the crab pot was supported by the hook mechanism and the subject provided the shaking force for ten seconds (right frame of Figure 14.)

Figure 14. Shake pot task (left without hook (no intervention), right with hook support (intervention).

Results

The lab evaluations of the hook support intervention for the shake crab pot task showed a significant effect ($p<0.01$) of the hook intervention on the activation levels of the right and left erector spinae and the right anterior deltoid, but interestingly not the left anterior deltoid (Table 3 and Figures 15 and 16) This non-significant effect on the average NEMG of the left anterior deltoid can be attributed to the technique that the subjects used with the left arm being positioned close by the side of the torso during the shaking process in the no intervention condition.

Table 3: MANOVA and ANOVA results for normalized EMG for the Shake Crab Pot intervention

Independent Variable	EMG	MANOVA	RES	LES	RRA	LRA	RAD	LAD	RPD	LPD
Intervention (Hook Support)	Peak	***	***	***			**	*	**	*
	Avg	***	***	***		*	*		***	***

**p < 0.05, **p < 0.01, ***p < 0.001*

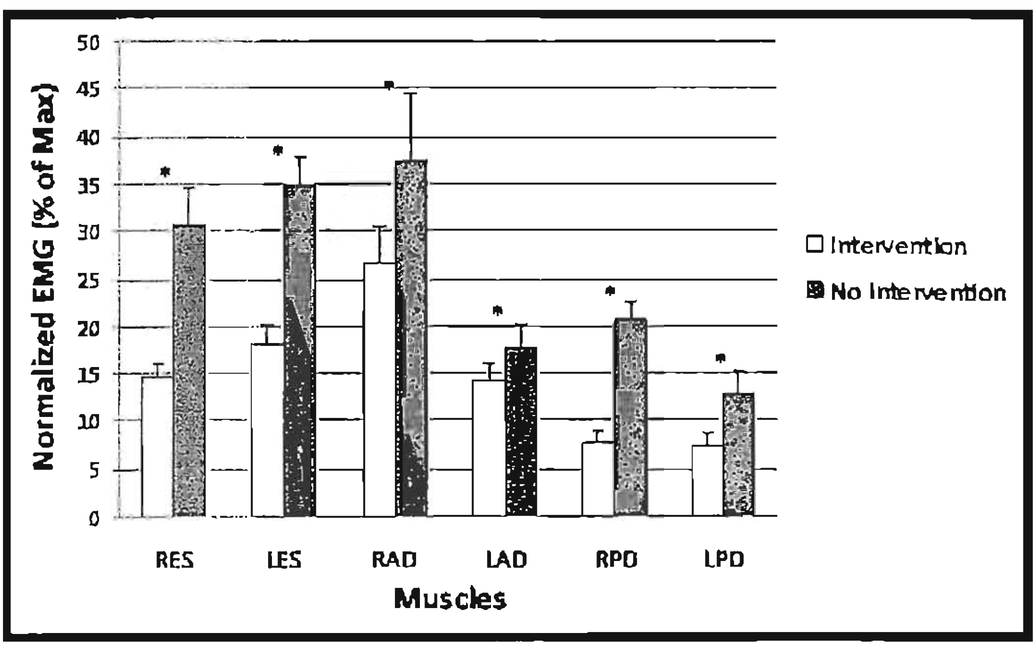


Figure 15. Significant effect of Intervention on peak muscle activities during the Shake Crab Pot task.

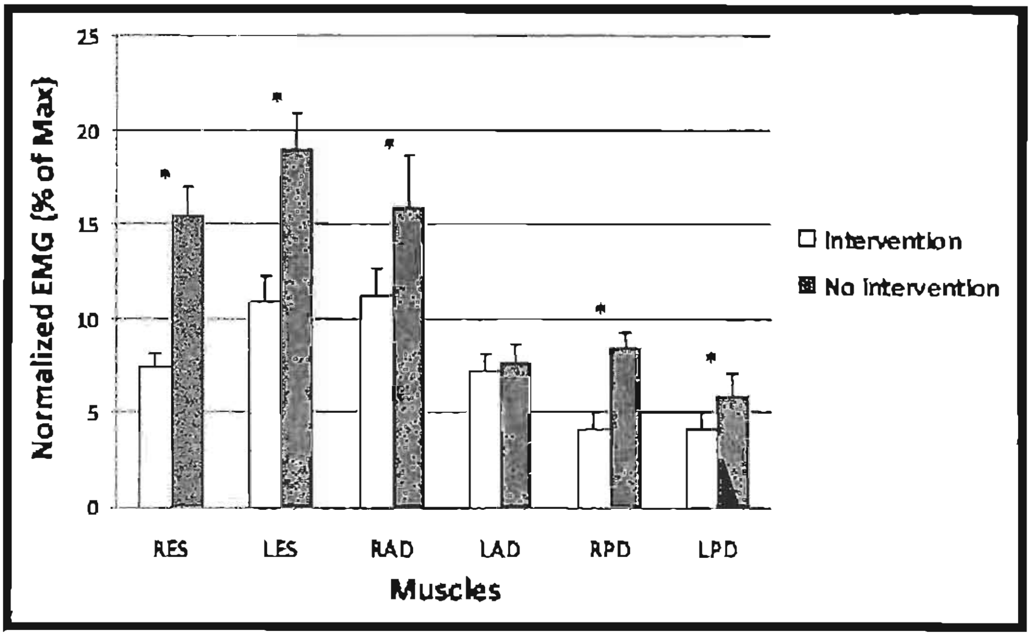


Figure 16. Significant effect of Intervention on average muscle activities during the Shake Crab Pot task.

Results

The field evaluation of this intervention (Figure 17) generated good evaluations. In all cases the fishermen felt that the intervention accomplished what it intended to accomplish – reduce stress on the back. The one observation for improvement was a suggestion to lower the hooks even further to avoid the need to lift the crab pot higher to attach to the hook system. The system that we used in the field did have some adjustability, but the fishermen felt that the lower the hooks the lower the level of shoulder and low back stress levels. As noted above, the system uysed in these field evaluations was a two-hook system that provided considerably more stability during the hooking and unhooking operations.

The end result of these field research consultations was that the device 1) achieves its biomechanical goals and 2) could be modified with a wider range of adjustability to meet the needs of the fishermen.

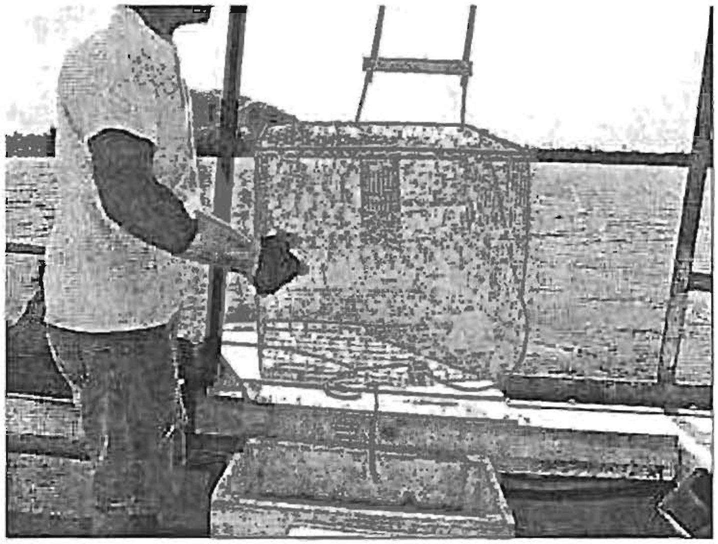


Figure 17. Commercial crab fisherman using the hook support intervention for the shake crab pot task.

4. Task #4: Sort Crabs

4.1. Description of Task

In this task the fisherman

1) Bends over to locate hands within the crab box,
2) Grabs those creatures that are not crabs and tosses overboard,
3) Grabs crabs that are too small and tosses overboard, and
4) Identifies and removes the soft shell crabs and places in a separate crab box

4.2. Motivation for Intervention

Review of the injury data and interviews with fishermen indicated that mates have a high prevalence of low back problems and the biomechanical analyses of the tasks performed by these fishermen indicated that this particular task was high risk for low back injury because of the extreme trunk flexion posture that is assumed for extended duration within the work cycle. (Figure 18.)

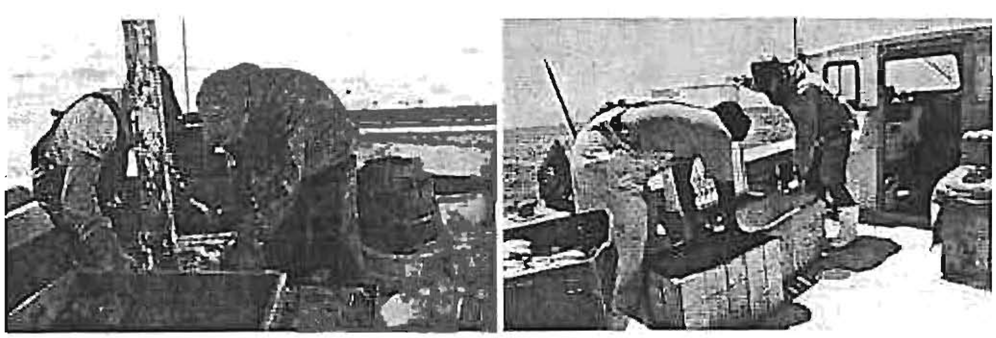


Figure 18. Sorting the crabs.

4.3. Ergonomic Intervention
The typical procedure is for the fisherman to bend over to mid-shank level and sort through the catch. In the intervention condition a false-bottom topper is placed on top of the crab box which allows the fisherman to assume a much more upright posture during this work task. (Figure 19). The height of this topper is set so that it is at the same height as the washboard of the fisherman's boat so that the hook support mechanism (Intervention #3) positions the crab pot directly over the topper.

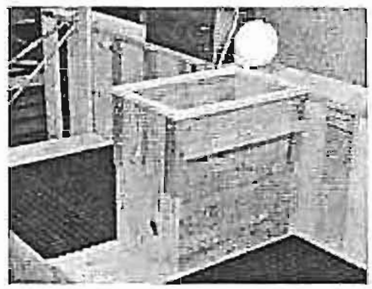


Figure 19. The crab box, false-bottom topper ergonomic intervention.

4.4. Evaluation of Intervention

Experimental Design

In the sort crab task one independent variable was considered: intervention (intervention or no intervention.) There was one dependent variable considered in this task: the average sagittal flexion angle during the sorting task. This was captured using a sagittal plane digital picture. The mock-up of the intervention used in the laboratory testing of this intervention is shown in Figure 20. In the no-intervention condition, the subjects worked at the mid-height within the crab box. (left frame of Figure 20.) In the intervention condition the subjects worked at the mid-height within the topper (right frame of Figure 20.)

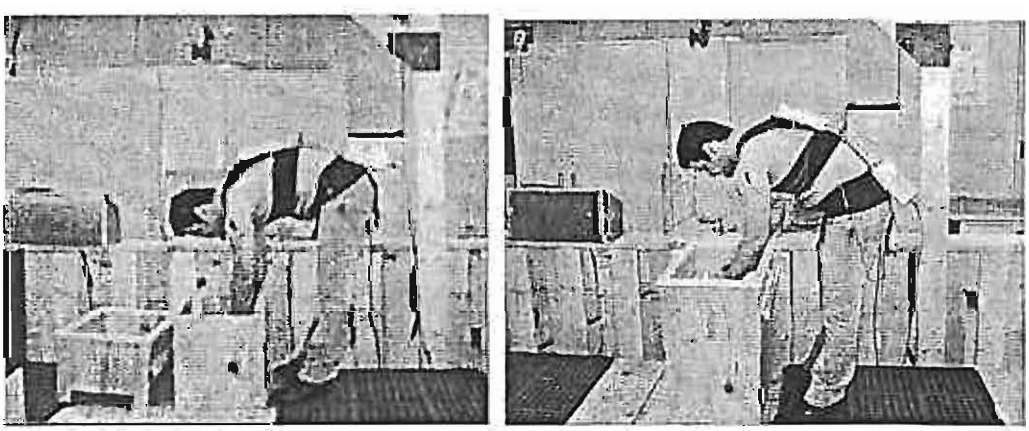


Figure 20. Sort crab task (left without topper (no intervention), right with topper (intervention)).

Results
The lab evaluations of the sort crab intervention showed a consistent and significant ($p<0.05$) improvement in the required sagittal flexion angle during the sorting crab tasks Figure 21)

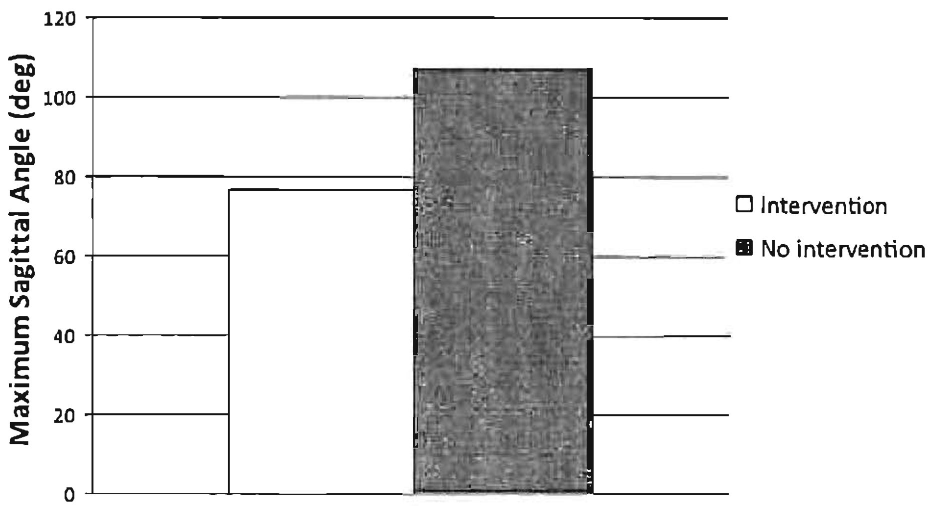


Figure 21. Significant effect of Intervention on average sagittal angle Sort Crab task.

5. **Task #5: Wash Crab Pots**

5.1. Description of Task

This particular intervention was less an intervention to address a standard cyclical task performed by these fishermen, and more an intervention designed to reduce the musculoskeletal stress during handling of the crab pots. In our conversations with some of the fishermen they noted that the weight of the crab pots was increased significantly (up to 5 additional pounds) as barnacles attached themselves to the wire mesh of the crab pots. They also said that they thought that these barnacles also reduced their catch, but that taking the time to remove the crab pots from the water was also reducing their productivity. They also told us that it was an extremely time consuming process to remove the barnacles from the pots. They either used a dipping process where the pots were dipped into a high chlorine concentration and then let air dry, followed by a quick washing with a pressure washer, or they simply used the pressure washer to blast the barnacles from the pots. If the latter methods was employed the fishermen estimated that this process could take up to 12 minutes per pot. If the former technique was used, they were concerned about breathing the chlorine fumes and it was still a time intensive task.

5.2. Motivation for Intervention
Review of the injury data and interviews with fishermen indicated that the fishermen had a high prevalence of low back problems and shoulder problems and the biomechanical analyses of the tasks performed by these fishermen indicated that many of the tasks involved the handling of these pots. Anything that could be done to reduce the weight of the crab pots could have a significant effect on the cumulative loading of the musculoskeletal system.

Figure 22. A barnacle-encrusted crab pot.

5.3. <u>Ergonomic Intervention</u>

The ergonomic intervention developed and tested in this study was a high pressure washing station. In the typical pot washing session the fishermen would have to stand and manually wave the pressure washer wand over the surface of the crab pots, making multiple passes over each section of the crab pots to blast the barnacles off of the wire surface. The intervention that was developed as part of this project was a washing chamber in which the crab pot hung and the pressure washer nozzle was mounted on the top of the chamber (Figure 23). This chamber was 48" high and 36" in diameter and utilized a pressure washer that pumped four gallons per minute and had a maximum pressure of 4500 psi. If this chamber model worked for washing the crab pots, the fisherman could put the crab pot into the chamber, activate the pressure washer and then walk away and perform other on-shore work tasks while the pressure washer would clean the pots.

Figure 23. The crab pot washing chamber.

5.4. Evaluation of Intervention

This intervention was only evaluated in the field. The intervention was used by the fishermen on the dock at their boathouse. Our approach was simply use different nozzles and different levels of pressure of the pressure washer to attempt to blast the barnacles off of the wire of the crab pots.

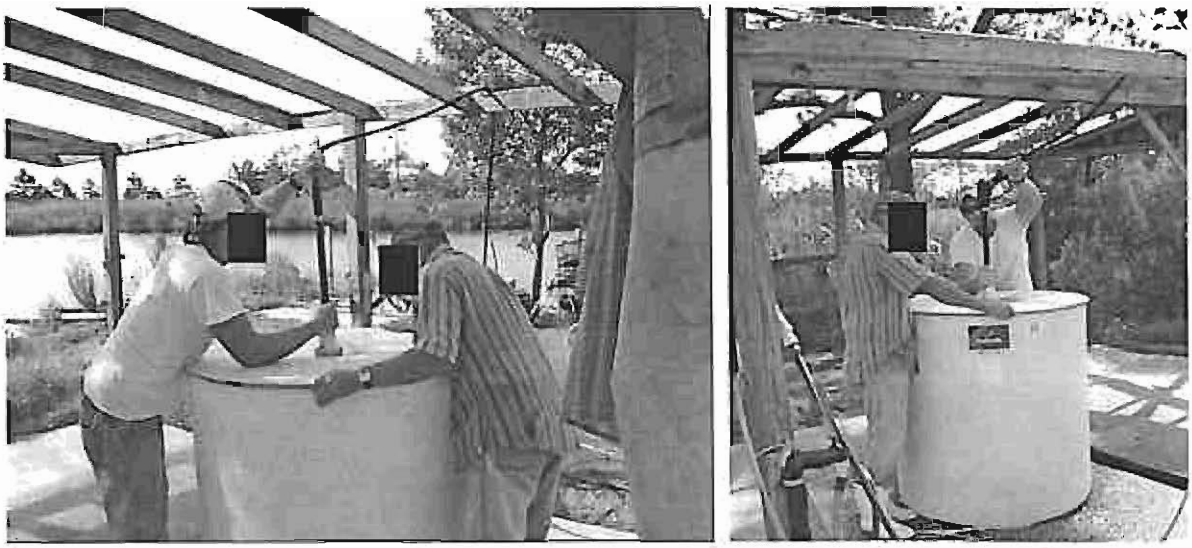


Figure 24. Two fishermen working with the crab pot washing chamber

Results

The ineffectiveness of the crab pot washing chamber was disappointing. Even at the highest pressures, the barnacles were still too tough for them to be removed from the wire (Figure 25.) In this figure one can see a small path of removed barnacles along the pot surface. Unfortunately, we were not able to adjust the height of the pot within the chamber such that it still maintained the necessary pressure while providing a broader spraying area for a more uniform cleaning. We came to the conclusion that the manual method of pressure washing the crab pots was the only feasible method for effective cleaning.

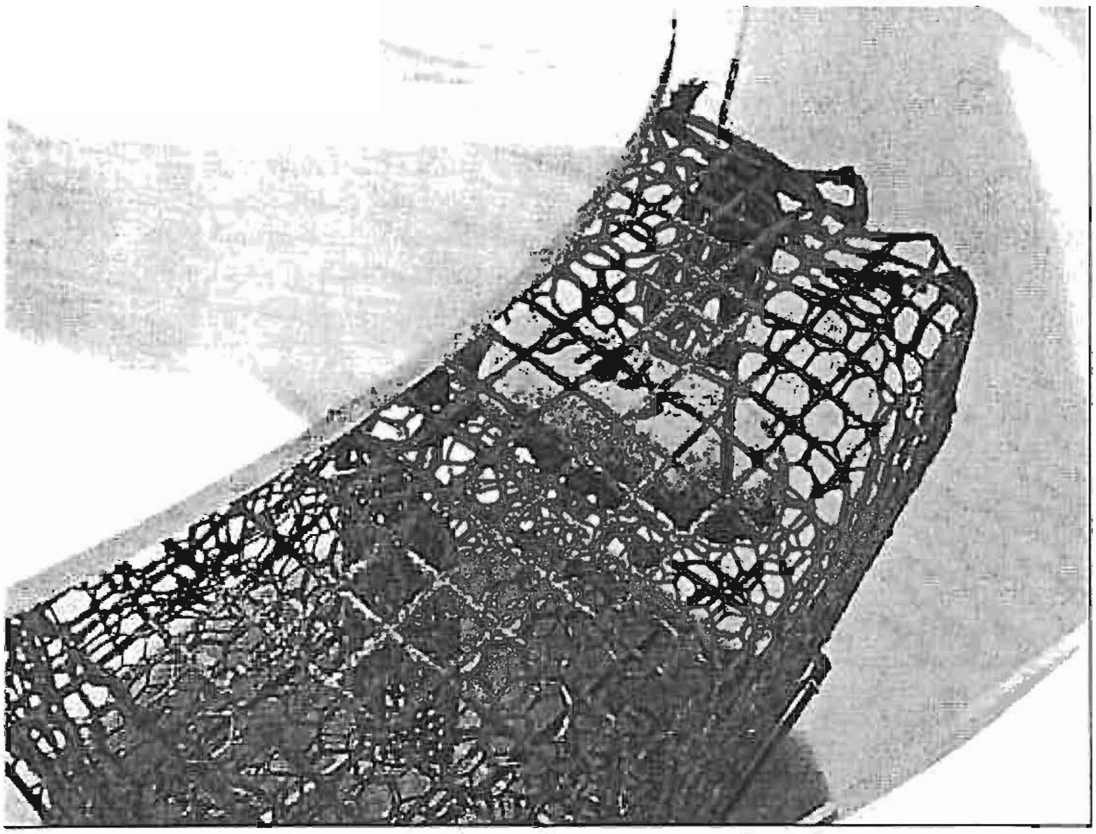


Figure 25. The crab pots after being mounted in the chamber for four minutes of washing.

PUBLICATIONS

Archival Journal Articles In Print

1. Kucera, KL, D Loomis, HJ Lipscomb, SW Marshall, GA Mirka, and J Daniels (2009) "Ergonomic Risk Factors for Low Back Pain in North Carolina Crab Pot and Gill Net Commercial Fishermen", *American Journal of Industrial Medicine*, 52(4): 311-321. ***This paper documents the results of our analysis related to Specific Aim #1. This paper documents the survey and interview methodologies used to obtain a profile of the workers in this industry. This includes the subjective assessments of these workers as to the causes of some of their work-related musculoskeletal disorders.***

2. Kucera KL, GA Mirka, D Loomis, SW Marshall, HJ Lipscomb, and J Daniels (2008) "Evaluating Ergonomic Stresses in North Carolina Commercial Crab Pot and Gill Net Fishermen", *Journal of Occupational & Environmental Hygiene*, 5(3): 182-196. ***This paper documents the results of our analysis related to Specific Aim #2. In this paper we document the evaluation of the individual work tasks performed by these workers using both the PATH methodology as well as the CABS methodology.***

Archival Journal Articles In Press

1. None

Archival Journal Articles In Review

1. Ning, X, and Mirka GA (In Review) "The Effect of Sinusoidal Rolling Ground Motion on Lifting Biomechanics", Submitted to *Applied Ergonomics*. ***This paper documents the results of our analysis related to Specific Aim #2. In this paper we explore the challenges associated with performing lifting tasks on moving ground surfaces as seen on these commercial fishing vessels.***

2. Jin, S and Mirka GA (In Review) "The Effect of a Lower Extremity Kinematic Constraint on Lifting Biomechanics", Submitted to *Ergonomics*. ***This paper documents the results of our analysis related to Specific Aim #2. In this paper we evaluated the lifting technique employed by many fishermen wherein they lean against the side of the boat as they pull the crab pots from the water.***

Refereed Conference Proceedings In Print

1. Mirka, GA and X Ning, "Ergonomic Interventions for Commercial Crab Fishermen" Industrial Engineering Research Conference, Miami, FL May 30-June 3, 2009. ***This paper documents the results of our analysis related to Specific Aim #3. In this paper we documented the specific ergonomic interventions that we developed to reduce the stress on the musculoskeletal system and then presented the results of the laboratory evaluation of these interventions using electromyography and motion analysis systems.***

2. Kucera KL, Loomis D, Lipscomb HJ, Marshall SW, Mirka GA, Daniels J. Biomechanical risk factors for low back pain in North Carolina crab pot and gill net commercial fishermen. Presented at the Prevention of Work-Related Musculoskeletal Disorders (PREMUS) conference in Boston, MA, August 27-30, 2007.

This paper documents the results of our analysis related to Specific Aim #2. In this paper we document the evaluation of the individual work tasks performed by these workers using both the PATH methodology as well as the CABS methodology.

3. Kucera KL, McDonald MA, Mirka GA. Occupational Stressors Identified by North Carolina Commercial Crab Pot Fishermen. Presented at the Fishing Industry Safety and Health conference (IFISH4), Reykjavik, Iceland, May 11-14, 2009.
This paper documents the results of our analysis related to Specific Aim #2. In this paper we document the evaluation of the individual work tasks performed by these workers using both the PATH methodology as well as the CABS methodology.

INCLUSION OF GENDER AND MINORITY STUDY SUBJECTS

Study Title: ERGONOMIC INTREVENTIONS FOR COMMERCIAL FISHERMEN

Total Enrollment: 199 **Protocol Numbers:** NCSU 213-06-6:ISU 7-346:8-181;9-244:9-265

Grant Number: OH08249

PART A. TOTAL ENROLLMENT REPORT: Number of Subjects Enrolled to Date (Cumulative) by Ethnicity and Race				
Ethnic Category	**Females**	**Males**	**Sex/Gender Unknown or Not Reported**	**Total**
Hispanic or Latino	0	0	0	0 **
Not Hispanic or Latino	8	115	1	124
Unknown (individuals not reporting ethnicity)	0	7	0	7
Ethnic Category: Total of All Subjects*	8	122	1	131 *
Racial Categories				
American Indian/Alaska Native	0	1	0	1
Asian	0	38	0	38
Native Hawaiian or Other Pacific Islander	0	0	0	0
Black or African American	0	0	0	0
White	8	82	1	91
More Than One Race	0	0	0	0
Unknown or Not Reported	0	1	0	1
Racial Categories: Total of All Subjects*	8	122	1	131 *

PART B. HISPANIC ENROLLMENT REPORT: Number of Hispanics or Latinos Enrolled to Date (Cumulative)				
Racial Categories	**Females**	**Males**	**Sex/Gender Unknown or Not Reported**	**Total**
American Indian or Alaska Native	0	0	0	0
Asian	0	0	0	0
Native Hawaiian or Other Pacific Islander	0	0	0	0
Black or African American	0	0	0	0
White	0	0	0	0
More Than One Race	0	0	0	0
Unknown or Not Reported	0	0	0	0
Racial Categories: Total of Hispanics or Latinos**	0	0	0	0 **

INCLUSION OF CHILDREN

In total there were seven children that participated in the research associated with this award. The survey work performed as part of Specific Aim #1 would indicate that only about 3% of the fishermen are between 18 and 21, so 3.5% appears to be a good representation in the study as a whole. The issues of overexertion injuries of the musculoskeletal system are thought to be more relevant to older populations, but the level of representation in the current study is appropriate and no significant age-related differences were found in the associated studies.

MATERIALS AVAILABLE FOR OTHER INVESTIGATORS

All materials from this study (survey data, intervention specifications, intervention effectiveness data) are available. Requests should be sent to Dr. Gary A. Mirka, Department of Industrial and Manufacturing Systems Engineering, Iowa State University, Ames, IA, 50011.