Use of the CABS methodology to assess biomechanical stress in commercial crab fishermen

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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 30 kg), dynamic exertions while pulling the crab pots from the water up into the boat and high loads (20–40 kg) 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 5 min 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.
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Keywords: Biomechanics; Low back injury; Commercial crab fishing

1. 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, b, 1979) or with

general safety issues facing the industry (e.g. Bull et al., 2001; Chiang 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)

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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 et al. (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 $0.6\,m \times 0.6\,m \times 0.5\,m$ 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 s. 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., 2000a, b) (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; Chaffin and Erig, 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 NIOSHLE, 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.

2. Methods

2.1. 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.

2.2. 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[TM], Triangle Research Collaborative, Inc., Research Triangle Park, NC) 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., 2000a). 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 LMM (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. Fig. 1 shows

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

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.

3. Results

Twenty-eight different subtasks were identified in the CABS analysis of a crabbing operation. Example results from nine 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.

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 Fig. 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.

When this analysis was performed on a crewmember-by-crewmember basis, differences in the stresses experienced by the individual are considerable. Figs. 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.

4. 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 NIOSHLE, 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

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)

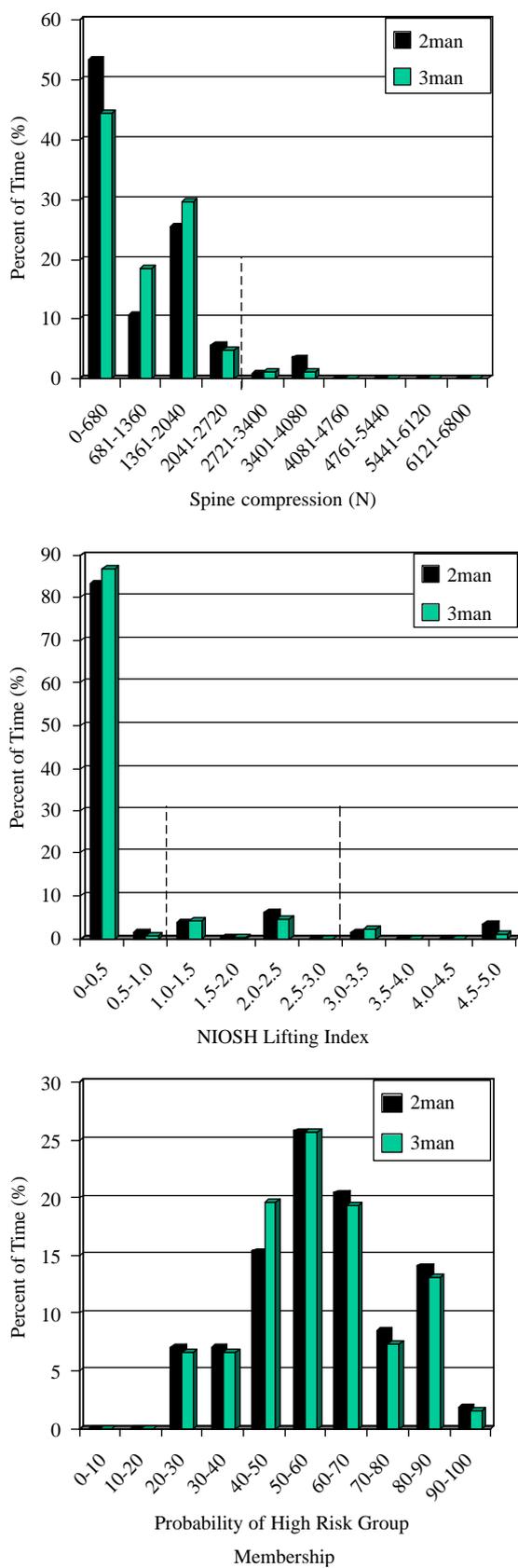|	PHRGM (%)	NIOSH LI	Spine Comp (N)
Get hook	54.5	0.18	824.9
Hook buoy	61.4	0.66	1503.2
Feed Pot Puller	30.6	0.17	574.3
Load bait on boat	84.3	3.30	3197.2
Lift pot into boat	79.3	1.23	2429.9
Unload catch	75.8	5.00	3937.7
Get bait	58.2	0.48	343.4
Load bait into pot	53.0	0.12	719.2
Sort crabs	41.4	0.09	1832.6

Fig. 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).

approach proved very valuable in previous ergonomic intervention research for the home building industry (Mirka et al., 1998; 2000a, 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 Figs. 3–5 illustrate considerable variability both between crewmembers (e.g. comparing captain vs. mate vs. third man in Fig. 3) as well as within a crewmember (e.g. the distribution of the data illustrated for the first man in Fig. 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 Fig. 5 is quite different from that in Figs. 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
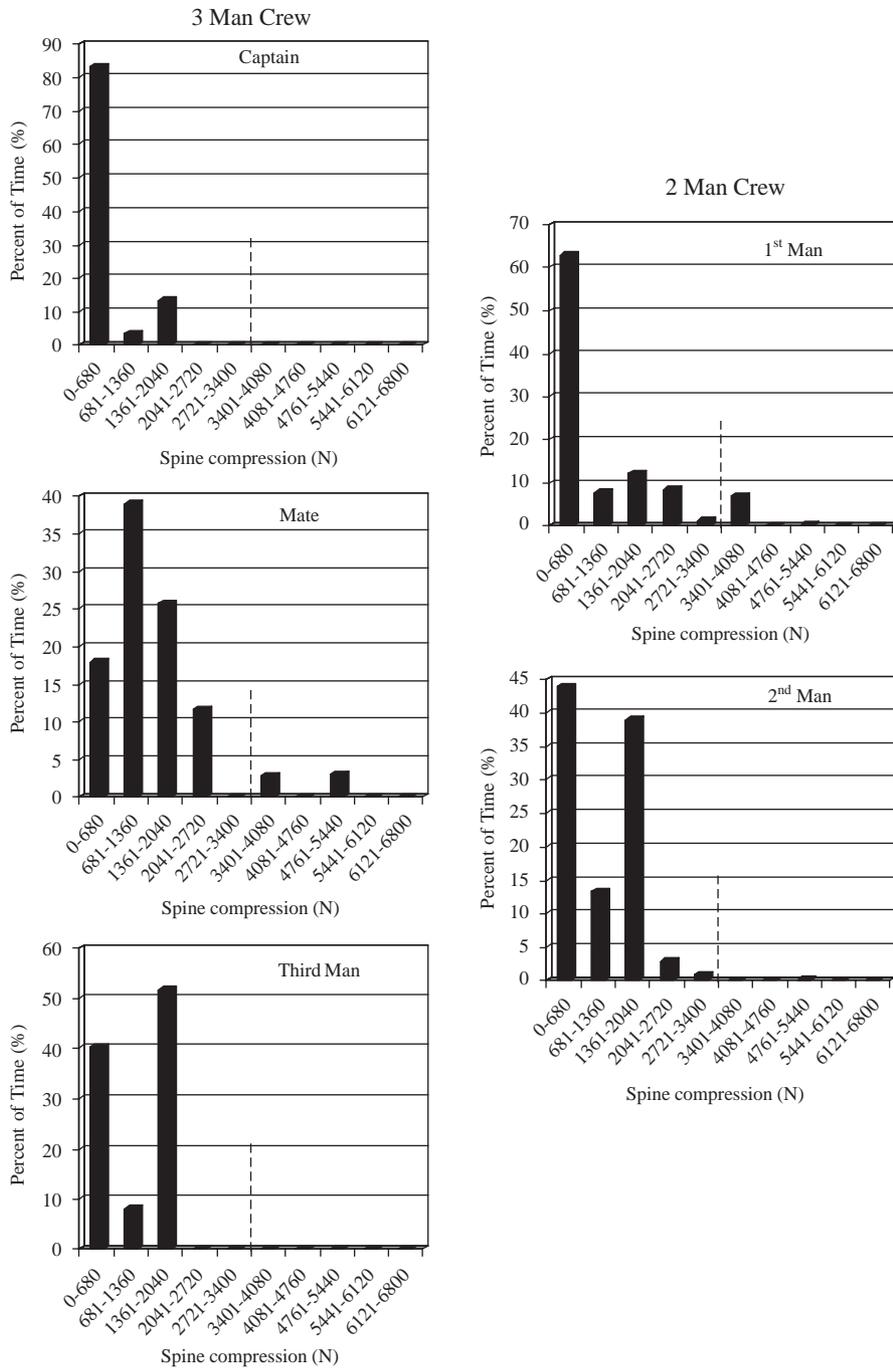
Fig. 3. Time-weighted distributions of spine compression by crew member for both the three (left) and two (right) man crews (vertical dashed lines provide reference to important assessment benchmarks).

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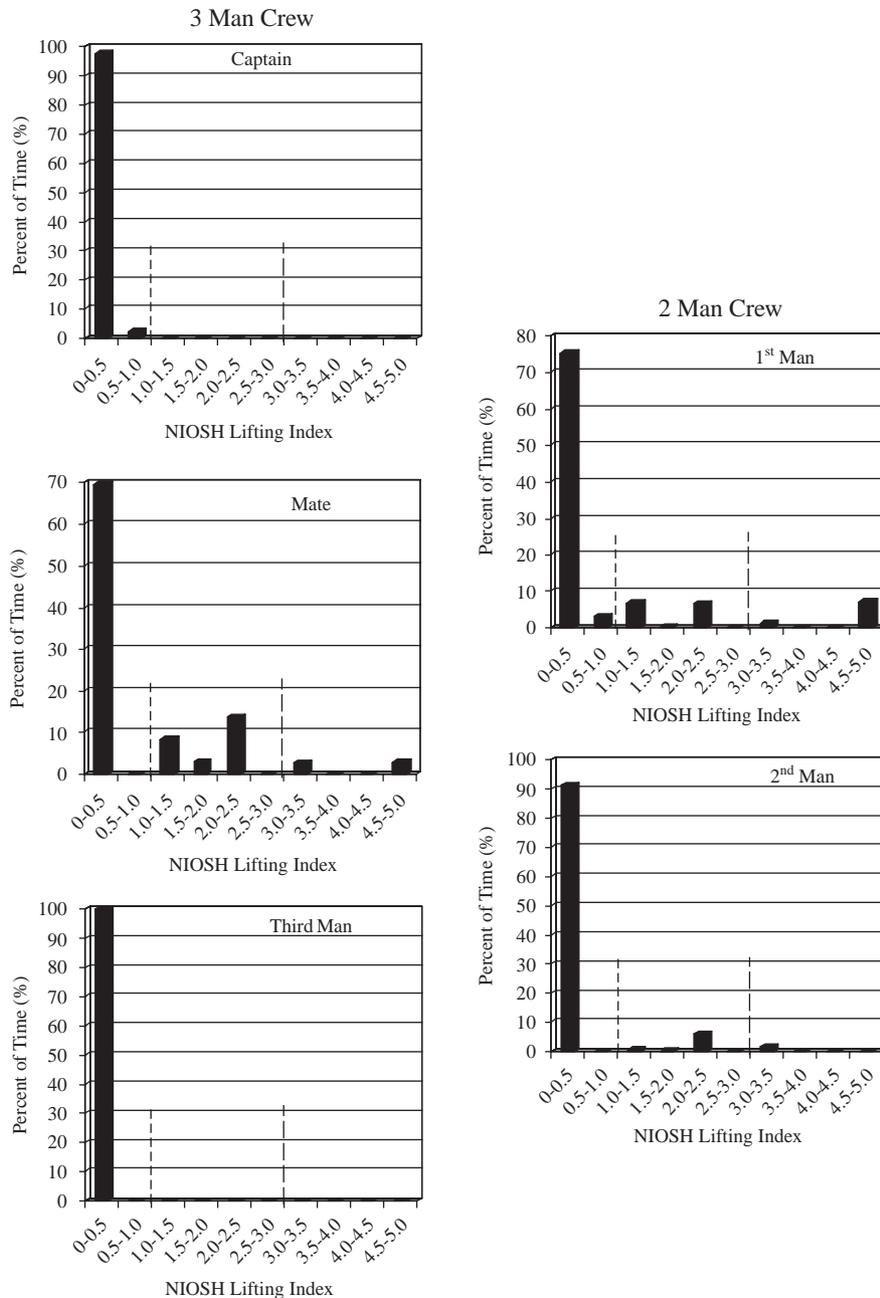
Fig. 4. Time-weighted distributions of NIOSH lifting index by crew member for both the three (left) and two (right) man crews (vertical dashed lines provide reference to important assessment benchmarks).

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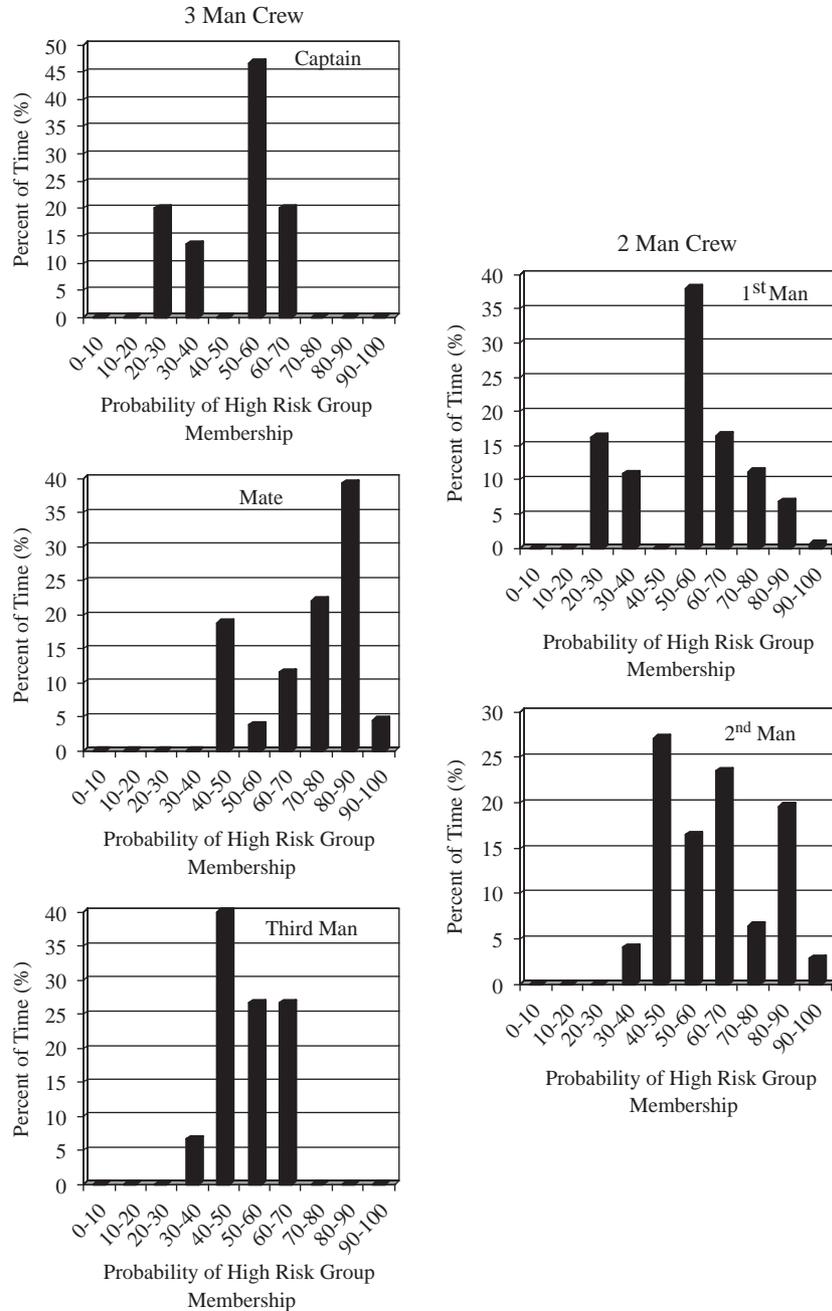
Fig. 5. Time-weighted distributions of probability of high risk group membership by crew member for both the three (left) and two (right) man crews.

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 2200 N) (Fig. 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 et al., 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 et al. (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.

5. 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.

Acknowledgments

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