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

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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 >9 kg, 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.

Keywords exposure variability, low back, mixed model, variance

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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 6 kg 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 I). 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.

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.

Because PATH samples postures and activities throughout the entire workday, quantification of the variability of postures and loads is possible.

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 subtasks, 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 >9 kg was 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:

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

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; $s_{j(km)}$ 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 (w_k), 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

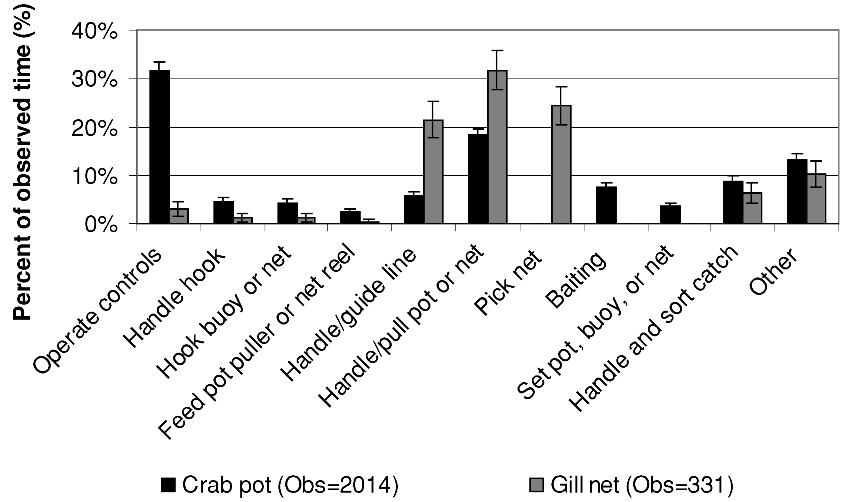

FIGURE 1. Percentage of time observed in commercial fishing activities for "pulling in gear" task by crab pot (n = 20) or gill net (n = 5) fishermen using Posture, Tools, Activities, and Handling (PATH) method.

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).

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

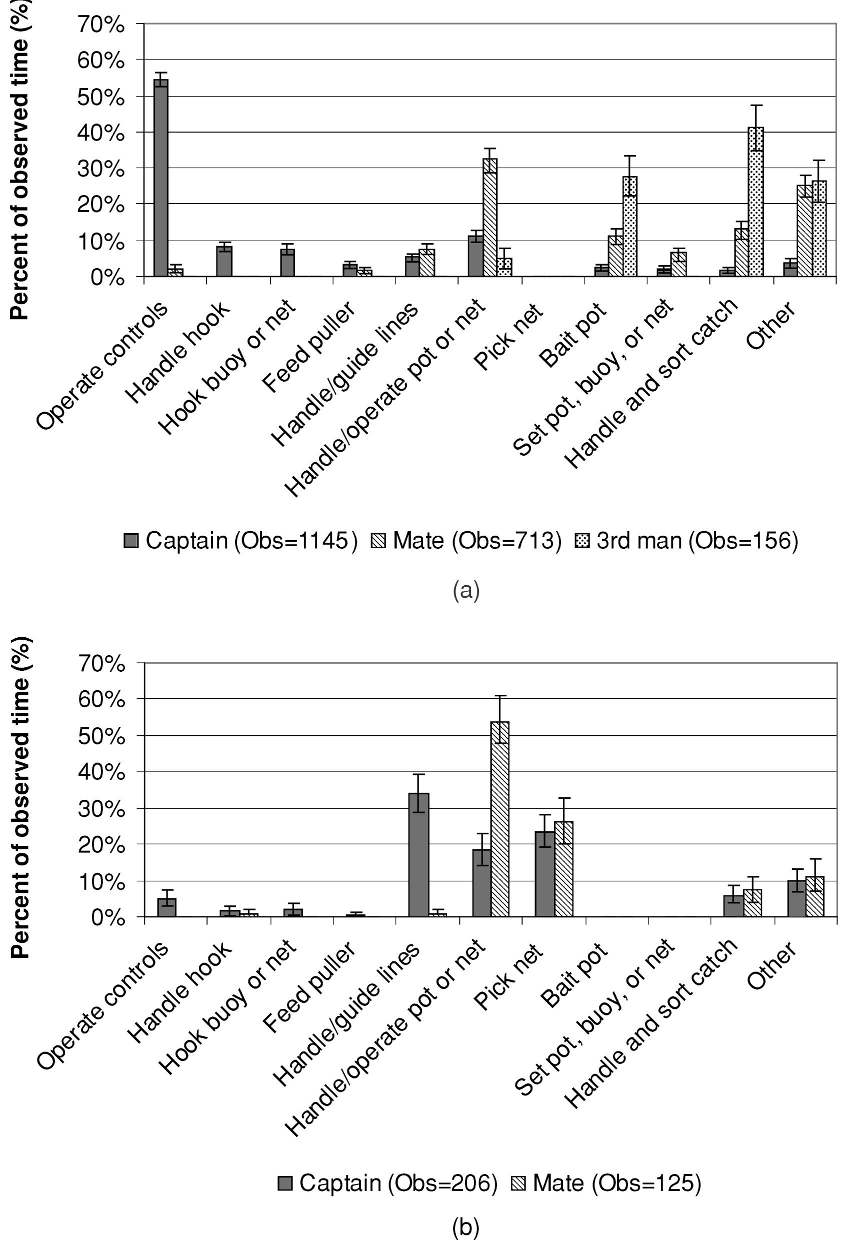

FIGURE 2. (a) Percentage of time observed in commercial fishing activities for task "pulling in gear" stratified by job title using Posture, Tools, Activities, and Handling (PATH) method—crab pot (10 captains, 6 mates, and 2 third men); (b) Percentage of time observed in commercial fishing activities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

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 (Table II). 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,

TABLE II. Selected Low Back Stress Measures for CABS Subtasks and PATH Task Activities

CABS				PATH				
Subtask	Compression^A (Newtons)	Lifting Index^B	Probability of High-Risk Group Membership^C Mean (range)	Task	Activity	Non-Neutral Trunk^D	Force >9 kg^D	Non-Neutral Trunk and Force >9 kg^D
Drive	311.4 (2.9)	0.0	—	Pull or set gear	Operate controls	6 (1.0)	0 (0.1)	0 (0.1)
Feed puller A, arms down, hook perpendicular to body	578.0 (24.3)	0.2	41.8 (30.5 to 52.1)	Pull or set gear	Feed puller	**33 (6.5)**	**29 (6.4)**	12 (4.4)
Feed puller B, one arm up, hook parallel to body	1372.4 (87.9)	0.3						
Grab 18 kg anchor, front of body	**3585.6 (280.8)**	2.2	**74.4 (64.8 to 84.9)**					
Grab 18 kg anchor, side of body	2846.5 (200.2)	**3.0**	**87.4 (80.3 to 93.8)**					
Grab rope and buoy with hand	2222.0 (187.7)	0.8	**72.2 (68.1 to 76.8)**	Pull or set gear	Grab rope with hand	**100 (1.1)**	**50 (17.7)**	**50 (17.7)**
Hook buoy A, one hand at side	1503.2 (104.2)	1.3	**84.2 (70.8 to 92.0)**	Pull or set gear	Hook buoy	**43 (5.2)**	**46 (5.2)**	12 (3.4)
Hook buoy B, two hands front	1137.6 (68.0)	0.4	**71.7 (58.5 to 84.4)**					
Lift down 18 kg basket	3239.6 (255.3)	1.7	**88.1 (82.5 to 92.3)**	Other^E	MMH^F = lower	**77 (11.7)**	**54 (13.8)**	**38 (13.5)**
Lift down 36 kg tote	**5314.9 (420.4)**	**3.3**	**81.5 (75.1 to 87.2)**					
Lift pot (>9 kg) to side of boat	2429.9 (178.3)	1.2	**83.1 (76.6 to 88.6)**	Pull or set gear	Handle/operate pot	20 (2.0)	**41 (2.5)**	10 (1.5)
Lift, tilt, and shake pot	1228.7 (77.0)	0.9	**84.5 (79.8 to 86.4)**					
Lift up 18 kg basket	**3624.5 (283.0)**	1.7	**89.0 (78.7 to 98.9)**	Other^E	MMH^F = lift	**58 (7.8)**	**55 (7.9)**	**35 (7.5)**
Lift up 36 kg tote	**4744.0 (371.0)**	**3.3**	-					
Pick net, bent posture	1529.8 (107.9)	0.1	46.3 (40.0 to 52.0)	Pull or set gear	Pick net	**41 (5.5)**	1 (1.2)	0 (0.4)
Pull net, bent posture	1507.6 (107.7)	0.8	**77.2 (60.5 to 87.8)**	Pull or set gear	Handle/pull net	**30 (4.3)**	7 (2.4)	4 (1.9)
Pull pot in by hand	1998.2 (142.3)	1.1	**78.1 (72.7 to 86.9)**					
Sort crabs	1833.0 (132.7)	0.1	52.3 (45.5 to 55.3)	Pull or set gear	Sort and cull catch	**83 (2.7)**	0 (0.2)	0 (0.2)
Turn and grab 36 kg tote	**3989.1 (318.6)**	**5.4**	—					

Note: Measures in **bold** considered to be higher risk for that exposure measure.

^A Low back compression measured in Newtons at L5/S1 joint with University of Michigan 3D Static Strength Prediction Program.[34,35]

^B NIOSH Lifting Index, object weight divided by recommended weight limit.[32]

^C Probability of high-risk group membership measured with Ohio State University Lumbar Motion Monitor.[33]

^D Percentage of sampled time during that PATH task and activity, % (se); non-neutral trunk includes flexion >20 degrees, bend and twist >20 degrees, or lateral flexion, bend, and twist >20 degrees.

^E Other PATH tasks include pre and post fishing, load and unload, and docking and casting off.

^F Manual materials handling and includes lift, lower, carry, push/pull, slide, or hold.

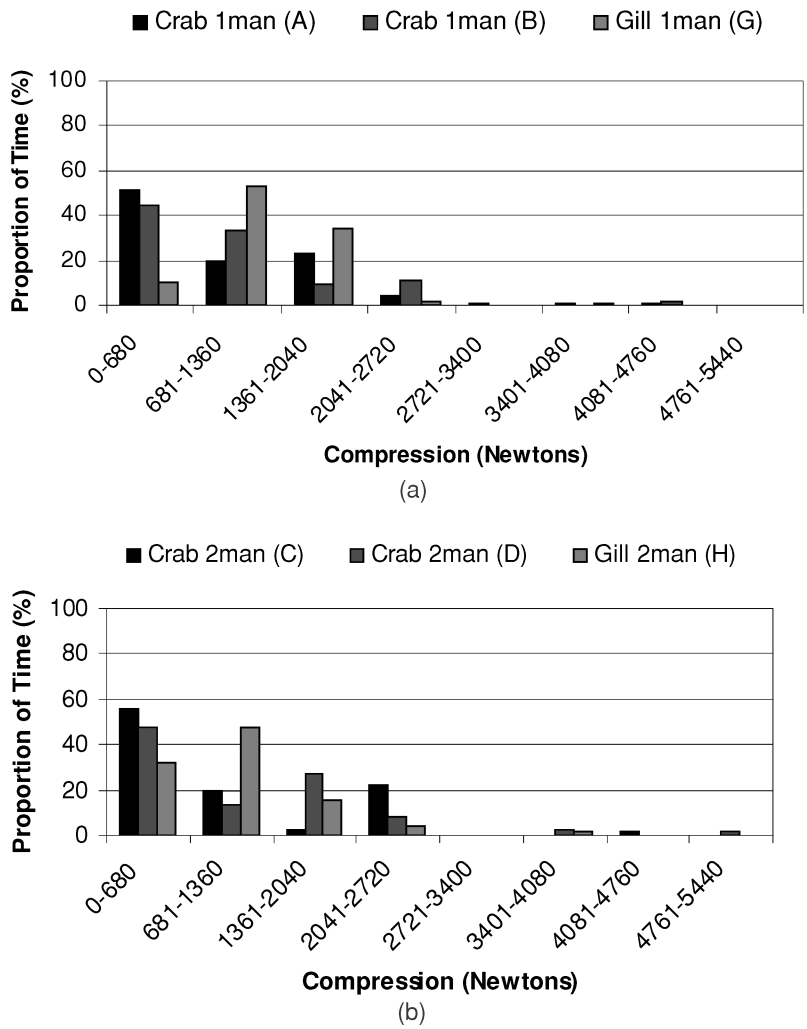

FIGURE 3. (a) Proportion of time for lumbar spine compression (Newtons) comparing 1-man crews between crab pot and gill net commercial fishing using Continuous Assessment of Back Stress (CABS) method; (b) Proportion of time for lumbar spine compression (Newtons) comparing 2-man crews between crab pot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

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 (Table II).

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 >9 kg (36.9%), non-neutral trunk plus force >9 kg (32.9%), lifting index >3.0 (29.8%), and spine compression >3400 N (53.9%) and 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 III and IV). 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

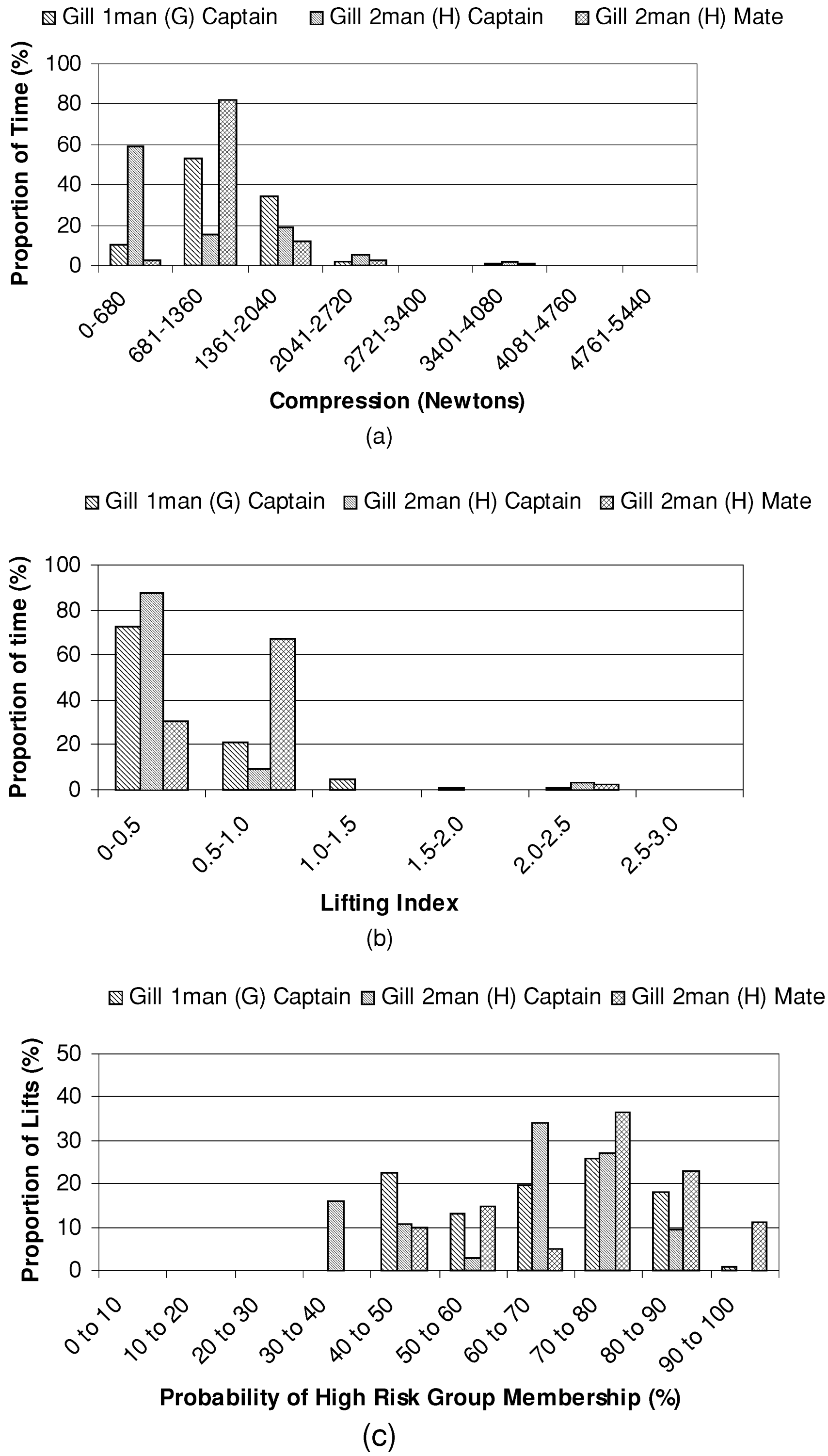

FIGURE 4. (a) Histogram of lumbar spine compression (Newtons) for gill net fishing captains and mates across different crew sizes using Continuous Assessment of Back Stress (CABS) method; (b) Histogram of NIOSH Lifting Index (LI) for gill net fishing captains and mates across different crew sizes using 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 III. 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 >9 kg (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 >9 kg (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
	σ^2_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^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 = 20 fishermen.
[A] Percentage of observed workday.
[B] Lift, lower, carry, push/pull, slide, or hold.

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.

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 >9 kg 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

TABLE IV. 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.

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 III and IV) but less so when examined between fishing types. Depending on how captains divided the work tasks in the current study, a 2-man 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.

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.

CONCLUSION

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.

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