Ergonomic Interventions for Commercial Crab Fishermen

Gary A. Mirka**, Xiaopeng Ning, Sangeun Jin,
Omid Haddad, and Kristen L. Kucera

The Ergonomics Laboratory
Department of Industrial and Manufacturing Systems Engineering
Iowa State University
Ames, IA 50011-2164, USA

** Corresponding author: Gary A. Mirka
Mailing address: The Ergonomics Lab, Dept IMSE, ISU, Ames, IA, 50011
Phone: 515-294-8661
Fax: 515-294-3534
e-mail: mirka@iastate.edu

Author: Xiaopeng Ning
Mailing address: The Ergonomics Lab, Dept IMSE, ISU, Ames, IA, 50011
Phone: 515-294-1682
Fax: 515-294-3524
e-mail: xpning@iastate.edu

Author: Sangeun Jin
Mailing address: The Ergonomics Lab, Dept IMSE, ISU, Ames, IA, 50011
Phone: 515-294-1682
Fax: 515-294-3524
e-mail: sjin@iastate.edu

Author: Omid Haddad
Mailing address: The Ergonomics Lab, Dept IMSE, ISU, Ames, IA, 50011
Phone: 515-294-1682
Fax: 515-294-3524
e-mail: ohaddad@iastate.edu

Author: Kristen Kucera
Mailing address: Duke Occup & Env Med, DUMC 3834, Durham, NC, 27710
Phone: (919) 286-3232
Fax: (919) 286-1021
e-mail: kristen.kucera@duke.edu

ABSTRACT

Work tasks in the commercial fishing industry require strength, endurance and coordination and these tasks 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 two simple ergonomic interventions to reduce exposure to these risk factors in small-scale commercial crab fishermen. 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 evaluation of the intervention designed to reduce the low back stress associated with hoisting the crab pots onboard showed significant reductions in muscle force requirements (erector spinae activity reduced by 25%) and peak sagittal trunk angle (reduced by 34%), while the results of the intervention designed to reduce shoulder stress during the process of shaking the crabs from the pots showed significant reductions in peak deltoid activity (reduced by 24%). A field test of these interventions provided a more subjective "usability" evaluation of the interventions. These responses were cautiously positive, providing insights into when these interventions would be most appropriate and under what conditions they would be more of a hindrance than a help.

Relevance to industry: Engineering controls are recognized as the most effective methods of reducing exposure to risk factors for musculoskeletal injury. Engineering controls were developed for small-scale commercial crab fishermen and these interventions were tested in the laboratory and in the field.

Keywords: commercial fishing; ergonomic intervention

1. Introduction

The commercial fishing industry is vital to the economy of many coastal communities in the United States. In North Carolina alone there were 5,947 commercial fishermen with the necessary licensure (North Carolina License and Statistics Section: Summary Statistics of License and Permit Program, 2008). The number of individuals actively engaged in commercial fishing work activities is considerably larger than this figure because commercial licenses are not required for crewmembers on fishing vessels or for those individuals that perform other support activities for the fishermen. These fishermen work long hours in a dynamic natural environment that can include excessive heat, frigid cold, high winds, precipitation of all sorts, and a wet, moving standing worksurface that creates unusual, three-dimensional inertial forces on loads. The physical demands of the work tasks require strength and endurance as well as high levels of coordination due the dynamic standing surface and expose these 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), slip and fall risks, and high levels of muscular fatigue.

The epidemiology literature supports the view that commercial fishing jobs pose significant challenges to the musculoskeletal system – particularly the low back region. In 1996, Jensen (1996) found that 10 percent of injuries in a Danish fisherman cohort were sprains and strains and 10 percent of the injuries involved the back. In a study of New Zealand commercial deep sea fishermen, Norrish and Cryer (1990) found that 39% of the compensated injury cases were recorded as having occurred during lifting, lowering, loading and unloading boxes. They further showed that back strains accounted for almost two-thirds of the strain or sprain injuries and 36% of the total costs. Recent studies indicate that back injuries remain an important outcome associated with accidents (Chauvin et al. 2007, Antao et al. 2008) and hospitalizations (Kaerlev et al. 2008) among commercial fishermen. Two questionnaire-based studies commercial fishermen from Sweden and the Southeastern US found that 74% and 84% reported musculoskeletal symptoms for any body region in the previous 12 months, with over half experiencing low back pain symptoms (Törner et al., 1988a, Lipscomb et al. 2004). Symptoms were also prevalent in the hand/wrist (21% Swedish fishermen and 40% Southeastern US), elbow and forearm (13% and 27%), shoulder (30% and 25%), and knees (25% and 29%). Of fishermen that reported symptoms, 25% of Swedish and 39% of Southeastern US fishermen indicated that these symptoms were at a level sufficient to limit their work activity in the last year, indicating a real economic cost associated with these symptoms.

Several recent studies provide deeper insights into the specific activities, exposures and challenges faced in the small-scale commercial crab fishing industry (Kucera et al., 2008, 2009, Kucera and McDonald, 2010, Lipscomb et al., 2004, Marshall et al., 2004, McDonald et al., 2004, Mirka et al., 2005). In 2008, Kucera and colleagues provided a detailed breakdown of the time that commercial crab fishermen spend performing the various work tasks and also documented how these breakdowns varied by position (captain, mate and 3rd man) (Kucera et al., 2008). These results provide a perspective on the exposures and activities and showed that much of the heavy manual materials handling was performed by the mate (hoisting the pots into the boat, shaking crabs from the pots, moving catch and bait around on the boat deck), while the third man often maintained static awkward postures while sorting the catch and the captain operated the controls and hooked the buoys. In a more recent survey-based study of 91 fishermen, Kucera and McDonald (2010) found that the most strenuous tasks identified by this cohort were pulling the crab pots from the water, emptying the catch from the pots, hooking the buoy, and moving boxes of catch and bait around on the boat deck. Supporting these subjective observations are the results of an earlier study (Kucera et al. 2009) that documented the relationship between physical activities of these fishermen and the rate of low back pain. Running the pot pullers or net reels, sorting catch, and unloading catch were associated with an increased rate of low back pain. More specifically, non-neutral trunk postures combined with a lifting force of greater than 9kg (>20 lb) showed the strongest relationship to low back pain (Kucera et al, 2009). These results and the epidemiological 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 acknowledged as the most effective way to reduce the incidence and severity of work-related musculoskeletal disorders through the reduction in exposure to recognized risk factors. Interventions employed in the commercial fishing industry have been successful in reducing the risk of entanglement and injury by installing an emergency stop (Lincoln et a, 2008). Two previous studies have considered 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. These authors identified a number of work factors (production speed, materials handling, etc.) that had an impact on the exposure to risk factors for these workers and conclude with a number of reasonable engineering control interventions. Unfortunately it was not within the scope of their study to perform a detailed evaluation of the effectiveness of these proposed interventions. Törner and colleagues, performed a practical ergonomic evaluation and intervention study among Swedish professional fishermen (Törner et al. 1988b). Intervention effects were evaluated through changes in muscle oxygen uptake and posture. Suggested interventions to reduce musculoskeletal stress included a modified vertical boat hull and manual winch for eel fishing and a dock-side crane for unloading the catch. The focus of the current study was the development and evaluation of ergonomic interventions designed to reduce exposure to recognized risk factors for the development of musculoskeletal disorders in the commercial crab fishing industry.

1.1 Introduction to Small-Scale Crab Pot Fishing

As an introduction to the methods employed in this study, we provide an overview of the sequence of tasks performed in a typical work cycle for a two-man crab pot fishing crew. 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 (see Figure 1 for a picture of a 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 (Figure 2) at about mid shin level to the interior of the boat. As the mate is lifting the pot into the boat he dumps the old bait from inside the crab pot. Once the pot is in the boat the mate shakes the crab pot vigorously (4-10 shakes) 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 throwing all but the "keeper" crabs overboard. (This sorting task is typically performed by the third man in a three man crew). At just about the time the mate has finished with this 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. As part of this project five engineering control interventions were developed. Two of these (Crab Pot Ramp and Crab Pot Boom) are presented in this paper.

Figure 1. Fisherman shaking crabs from a barnacle-encrusted crab pot.

Figure 2. Fisherman lifting the crab pot from the water.

2. Methods

2.1 Participants

Seven participants were recruited from the university student population. Subjects were all free from any low back or other musculoskeletal problems and all provided written informed consent prior to participation (approved by the Institutional Review Board of Iowa State University). The participant in the field study was an individual that had worked with the research team over several years, was familiar with the project and was willing to try out these interventions on his fishing vessel and provide feedback.

2.2 Experimental Apparatus for Laboratory Evaluation

As advocated by Dempsey (2007), our approach to evaluating the effectiveness of our proposed interventions was to evaluate the effects of our interventions on the exposure to known biomechanical risk factors of work-related musculoskeletal disorders. A mock-up of a commercial crab fishing boat (deck 4'wide x 12'long with 39" high side rails) was developed to provide a functional working environment for subjects performing the experimental tasks. Surface electromyography (EMG) (Delsys, Inc, Boston, MA, USA) and the lumbar motion monitor (LMM) (Chattanooga Group Inc., TN) (Marras et al., 1992) 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 and left pairs of the erector spinae (RES, LES), rectus abdominis (RAB, LAB), anterior deltoid (RAD, LAD), and posterior deltoid (RPD, LPD). Electromyographic data and LMM data were both collected for 10 seconds for each trial with frequency of 1024 Hz and 60 Hz, respectively.

2.3 Engineering Controls

2.3.1 Lift Crab Pot Task - Crab Pot Ramp

In this task the mate reaches over the side of the boat and grasps the crab pot (approximately mid-shin level), lifts the crab pot over the side of the boat, discards the old bait, and then unhooks a bungee cord to open the pot and allow the crabs to be shaken out of the pot. 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).

The engineering control developed to address these risk factors was a ramp system for bringing the crab pots out of the water up onto the washboard of the side of the boat. This ramp system is made of PVC piping, attaches to the side of the boat, and uses the pot puller mechanism to pull the crab pots up the ramp to approximately mid torso height (Figure 3).

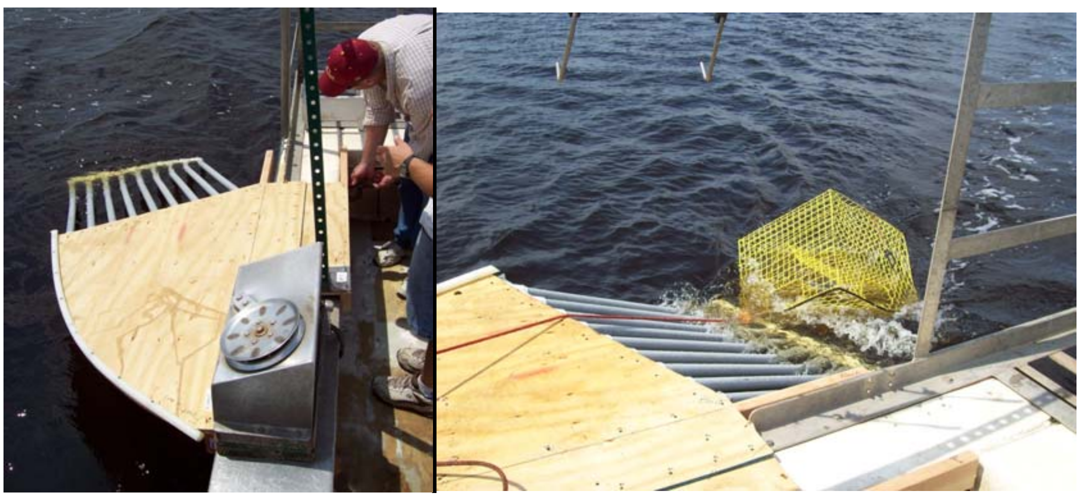

Figure 3. The Crab Pot Ramp intervention mounted to the side of the fishing boat.

2.3.2 Shake Crab Pot Task - Crab Pot Boom

In this task the fisherman lifts the crab pot from the washboard (picking up the where "lift crab pot" task ended), holds the crab pot over the crab box, and shakes the crabs out of the pot into the crab box. 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 (up to 80 Nm) when vigorously shaking these pots (Figure 1).

The engineering control developed to address these risk factors was 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. The boom system was made of 2”x2” square steel stock and was height adjustable. The hook system was comprised of two parallel hooks hanging from the boom arm and attached to the crab pots through stiff rubber straps that simultaneously allowed both rigidity and flexibility (Figure 4).

Figure 4. The Crab Pot Boom intervention mounted to the side of the fishing boat.

2.4 Experimental Design

The principal independent variable in each of these evaluations was INTERVENTION with two levels. In the first level, participants simulated the fishing task as it is typically performed without the intervention (no intervention condition). In the second level the task was performed using the engineering control developed (intervention condition). In the study of the Lift Crab Pot task an additional independent variable was considered: LOAD WEIGHT (9kg vs. 13.5kg). There were 17 dependent variables considered: the mean and peak normalized EMG activity of 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) and the maximum sagittal flexion angle.

2.5 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. Maximal trunk extension (erector spinae) and flexion (rectus abdominis) were performed while the participant maintained a 20 degree flexed posture, while the maximal shoulder exertions (deltoids) were performed with the shoulder abducted to 90 degrees in the coronal plane. After completing the maximal exertions, the participant then donned the LMM and was led onto the boat to perform the fishing tasks.

The first task performed was the Lift Crab Pot task. The laboratory mock-up of this intervention is shown in Figure 5. Subjects were instructed to stand facing the bow of the boat and then lift the crab pot from the designated location to an upright sagittally symmetric position. The location of the crab pot at the beginning of the lift simulated the location from which the fishermen would lift the crab pot in both the standard (over the side of the boat, hands reaching to mid-shin level) and intervention conditions (pot travelling up the ramp to a mid-chest position outside of the railing of the boat). There were two repetitions of each condition and the presentation order of the conditions was completely randomized. A rest period of 30 seconds was provided between conditions.

Figure 5. Starting position of the lift crab pot task using the current technique (left) and the intervention technique (right).

Upon completion of the Lift Crab Pot task the participant next simulated the Shake Crab Pot task. The laboratory mockup of this intervention is shown in Figure 6. Participants began the task with their hands on the crab pot and were instructed to shake the crab pot vigorously simulating the motions necessary to shake the crabs from the pots. In the no-intervention condition, the subjects supported the weight of the crab pot while shaking the pot for a period of ten seconds. 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. There were two repetitions of each condition and the presentation order of the conditions was completely randomized. A rest period of 30 seconds was provided between conditions.

Figure 6. Shake crab pot task (left without hook (no intervention), right with hook support (intervention).

2.5 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 1/8th second windows and the EMG data in these windows were averaged and the maximum of these windows was identified as the MVC level for that muscle). The "mean" EMG data reflects the arithmetic mean of all EMG data occurring during the work task, while the values described as "peak" are the largest of the 1/8th second windows occurring during the work task. Trunk kinematic data from the LMM were captured and the maximum angle in the sagittal plane was identified for each trial in the lift crab pot and sort crabs tasks.

All statistical analyses in this study were conducted using SAS (SAS Institute, Cary, NC). 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. Only those independent variables found to be significant in the MANOVA were pursued further in the univariate ANOVA. A criteria p-value of 0.05 was used in all statistical tests.

3. Results and Discussion

3.1 Crab Pot Ramp

The laboratory evaluation of the Crab Pot Ramp intervention showed significant, positive effects. The MANOVA revealed that the interaction between LOAD WEIGHT and INTERVENTION was not significant but both LOAD WEIGHT and INTERVENTION were significant main effects. Subsequent univariate analysis revealed that this intervention significantly reduced the muscle activity required to perform the task (peak erector spinae reduced by 25%, peak deltoid muscle activity reduced by 33%) (Table 1 and Figure 7) and it also reduced the peak sagittal angle required to reach the crab pots at the beginning of the lifting activity (Figure 8). The LOAD WEIGHT main effect was significant for all muscles except the right and left rectus abdominis. These results clearly show that the engineering control meets the objectives of reducing the stress on the musculoskeletal system.

Table 1: MANOVA and univariate ANOVA results (NT – not tested because MANOVA was not significant; NS not significant)

Lift Crab Pot Intervention

Independent Variable	NEMG	MANOVA	RES	LES	RRA	LRA	RAD	LAD	RPD	LPD	Peak Sag Angle
Intervention	Peak	***	***	***	***	***	***	***	***	***	***
	Mean	***	***	***	***	***	NS	***	***	***	
Load Weight	Peak	***	***	***	NS	NS	**	*	**	*	NS
	Mean	***	***	***	NS	NS	***	*	*	**	
Intervention × Load Weight	Peak	NS	NT	NT	NT	NT	NT	NT	NT	NT	NT
	Mean	NS	NT	NT	NT	NT	NT	NT	NT	NT	

Shake Crab Pot Intervention

Independent Variable	NEMG	MANOVA	RES	LES	RRA	LRA	RAD	LAD	RPD	LPD
Intervention	Peak	***	***	***	NS	NS	**	*	**	*
	Mean	***	***	***	NS	*	*	NS	***	***

$^*p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$

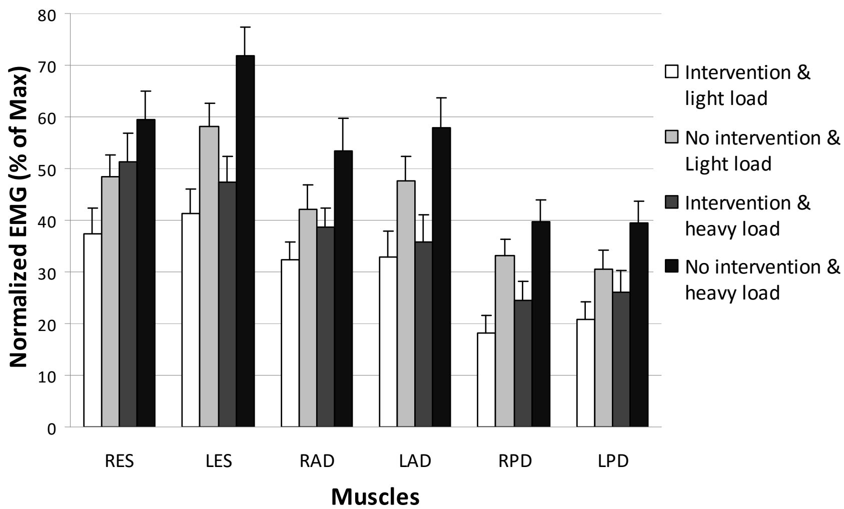

Figure 7. Significant effect of both INTERVENTION and LOAD WEIGHT on peak muscle activities during the lift-off phase of the lift crab pot task (standard error bars are shown.)

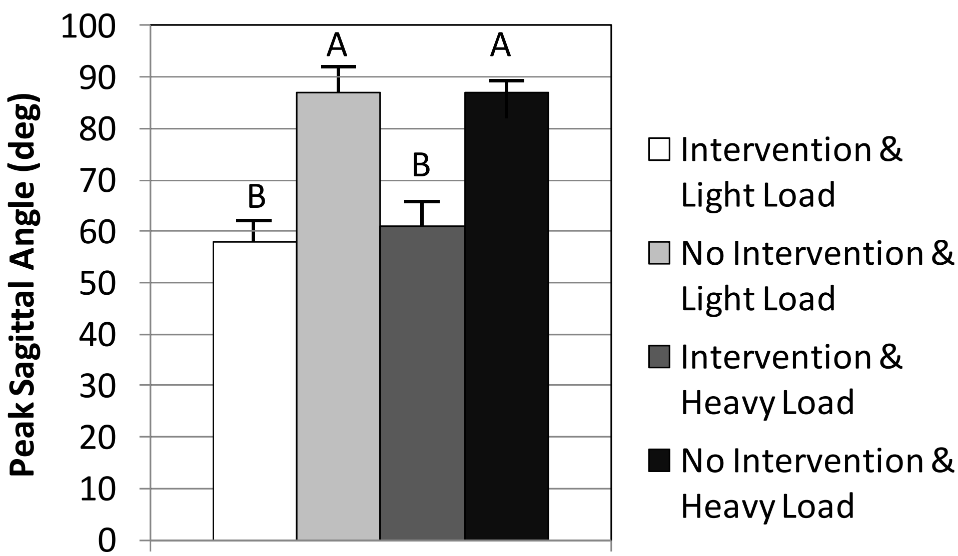

Figure 8. Significant effect of INTERVENTION on peak sagittal angle during the lift-off phase of the lift crab pot task (standard error bars are shown.).

Field testing of this intervention required that the fisherman mount the device to the side of his boat and work with this ramp system. The purpose was to begin to test the functionality of the system under realistic conditions and to gather some basic usability data. Figure 2 shows the device as mounted on the side of one crab fisherman's boat. The first figure shows the device mounted. The second figure shows the crab pot beginning its run up the PVC pipe ramp. The field testing of this intervention, which consisted of the fisherman pulling 20 pots, received a mixed evaluation. The fisherman 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. In 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 could work well. 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. This was particularly important because the fishermen consulted 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^{o} orientation of the PVC pipes to allow for a broader utility in the one-man crabbing operations and varied fishing conditions/ techniques.

3.2 Crab Pot Boom

The laboratory evaluation of the Crab Pot Boom intervention also showed significant, positive effects. The MANOVA revealed that the effect of INTERVENTION was a significant and subsequent univariate analysis revealed a significant reduction in the mean activation levels of the muscles of the right and left erector spinae (reduced by 51%) and the mean activation levels of the deltoid muscle groups (reduced by 24%) (Table 1 and Figure 9). The field testing of this intervention (Figure 4) generated a positive evaluation. The fisherman felt that the intervention accomplished what it intended to accomplish – reduce stress on the back and shoulders. The one observation for improvement was a suggestion to lower the hooks even further to avoid the need to lift the crab pot to attach to the hook system. The system that we used in the field did have some adjustability, but the suggestion was made that the lower the hooks, the lower the level of shoulder and low back stress levels. 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.

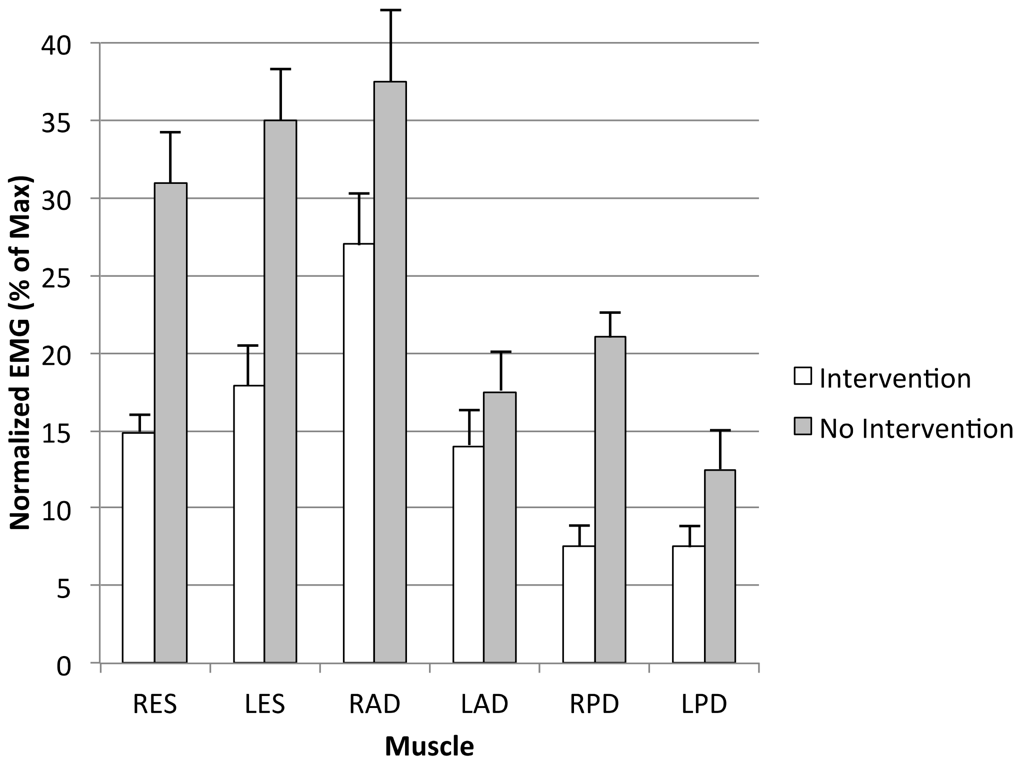

Figure 9. Significant effects of INTERVENTION on peak muscle activities during the shake crab pot task (standard error bars are shown).

3.3 Limitations and Strengths

This study has some limitations worth noting. Laboratory evaluations of the interventions were conducted with non-fisherman, student volunteers who simulated the fishing tasks in a lab rather than actual commercial fishermen performing tasks in their work setting. The purpose of the lab tests were to determine whether the intervention resulted in changes in muscle activity and the motions tested were fairly straight-forward (e.g., lift the pot into the boat, shake the pot). Even so, simulations represent estimates of the real work tasks and "true" kinematics. Due to study constraints, the interventions were tested in the field on one day with one fisherman. It is unknown how use of these interventions would impact the flow and speed of the crab pot fishing work. For example, the intervention may decrease physical stress, however may increase work time which would negatively impact the utility and acceptance of the intervention. Despite these limitations, this study builds from previous research with this population of small-scale fisherman and adds to the literature on interventions to reduce musculoskeletal stress in commercial fishing.

4. Conclusions

This study demonstrated the effectiveness of two ergonomic engineering controls for the reduction of exposure to risk factors for musculoskeletal disorders in commercial crab fishing. Two ergonomic controls were tested in both the laboratory and the field. A ramp system was designed and built to reduce the awkward trunk postures required to lift the crab pots from the water. A boom and hook system was designed and built to eliminate the required lifting force during the process of shaking the crabs from these crab pots. In the laboratory both devices demonstrated significant reductions in the required muscle forces necessary to perform the tasks. In the field, both devices were viewed as positive improvements for select populations (e.g., an older fisherman fishing alone, straight-line crab fishing methods) and valuable insight with regard to further improvements to make these devices more universally useful was gained. Further investigation could provide more data relative to the cost-effectiveness of these and other interventions for these fishermen.

Acknowledgements

This work was supported by Grant No. R01 OH08249 from the National Institute for Occupational Safety and Health (NIOSH). The contents are solely the responsibility of the authors and do not necessarily reflect the views of NIOSH.

References

Antão, P., Almeida. T., Jacinto. C., Guedes Soares, C., 2008. Causes of occupational accidents in the fishing sector in Portugal. Safety Science 46(6), 885-899.

Chauvin, C., Le Bouar, G., 2007. Occupational injury in the French sea fishing industry: a comparative study between the 1980s and today. Accident Analysis and Prevention 39(1), 79-85.

Dempsey, P.G., 2007. Effectiveness of ergonomics interventions to prevent musculoskeletal disorders: Beware of what you ask. International Journal of Industrial Ergonomics. 37, 169-173.

Fulmer, S., Buchholz B., 2002. Ergonomic exposure case studies in Massachusetts fishing vessels. American Journal of Industrial Medicine. 42, 10-18.

Jensen, O., 1996. Work related injuries in Danish fishermen. Occupational Medicine. 46, 414-420.

Kaerlev, L., Jensen, A., Nielsen, P., Olsen, J., Hannerz, H., Tuchsen, F., 2008. Hospital contacts for injuries and musculoskeletal diseases among seamen and fishermen: A population-based cohort study. BMC Musculoskeletal Disorders 9(1), 1-9.

Kucera, K.L., Loomis, D., Lipscomb, H.J., Marshall, S.W., Mirka, G.A., Daniels, J., 2009. Ergonomic risk factors for low back pain in North Carolina crab pot and gill net commercial fishermen. American Journal of Industrial Medicine. 52, 311-321.

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 & Environmental Hygiene. 5, 182-196.

Kucera, K.L., McDonald, M.A., 2010. Occupational stressors identified by small-scale, independent commercial crab pot fishermen. Safety Science. 48, 672-679.

Lincoln, J.M., Lucas, D.L., McKibbin, R.W., Woodward, C.C., Bevan, JE., 2008. Reducing Commercial Fishing Deck Hazards with Engineering Solutions for Winch Design. Journal of Safety Research 39(2), 231-235.

Lipscomb, H.J., Loomis, D., McDonald, M.A., Kucera, K.L., Li, 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., 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.

Marshall, S.W., Kucera, K.L, Loomis, D., McDonald, M.A., Lipscomb, H.J., 2004. Work-related injuries in small-scale commercial fishing. Injury Prevention. 10, 217-221.

McDonald, M.A., Loomis, D., Kucera, K.L., Lipscomb, H.J., 2004. Use of qualitative methods to map job tasks and exposures to occupational hazards for commercial fishermen. American Journal of Industrial Medicine. 43, 23-31.

Mirka, G.A., Shin, G., Kucera, K.L., Loomis, D., 2005. Use of the CABS methodology to assess biomechanical stress in commercial crab fishermen. Applied Ergonomics. 36, 61-70.

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.

North Carolina License and Statistics Section: Summary Statistics of License and Permit Program. Moorhead City, NC: License and Statistics Section, North Carolina Division of Marine Fisheries; Report date: October 27, 2008, pp 431 (available at: http://www.ncfisheries.net/download/2008BigBook.pdf).

Törner, 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, 191-201.

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