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ORIGINAL RESEARCH

Characterization of Musculoskeletal Injury Risk in Dungeness Crab Fishing

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ABSTRACT

Objectives: Commercial Dungeness crab fishermen's manual crab pot handling activities can be done in harsh outdoor working environments at sea and can pose well-known physical risk factors associated with musculoskeletal injury including forceful exertion, repetition and awkward posture. The nonfatal injury rate in this fishing fleet is 3.4 per 1,000 full-time equivalent workers. Two-thirds of self-reported injuries in the fleet were musculoskeletal sprains and strains. To date, no objective biomechanical assessment of musculoskeletal disorder (MSD) risk has been conducted due to the challenging work environment.

Methods: The aim of this study was to determine the feasibility of collecting objective biomechanical assessments (i.e., posture and repetition) using inertial measurement unit (IMU) sensors placed on the arms and torso of professional deckhands (n = 7) while at sea, harvesting Dungeness crab. Based on the IMU-measured posture data, fishermen's anthropometry, and crab pot weights, biomechanical loading of the low back and both shoulders was estimated.

Results: The IMU sensor data showed that commercial Dungeness crab fishing is highly repetitive and poses awkward postures in the shoulders and back. The estimated static low back compression, shear force, and flexion moment about the shoulders and low back (L5/S1) indicate potential injury risk associated with harvesting crab.

Conclusion: The results indicate that objective biomechanical assessment using the IMU sensors is feasible in the commercial fishing environment.

ARTICLE HISTORY

KEYWORDS
Inertial measurement unit; posture; repetitive motion

Introduction

Commercial Dungeness crab fishing is a physically demanding and dangerous occupation due to high rates of fatalities and injuries.[1–5] In a review of US Coast Guard reported traumatic injuries (2002–2014) of fishermen in this fleet, the average fatality rate in Dungeness crab fishermen is 209 per 100,000 full-time equivalent (FTE) workers,[1] which is substantially higher compared to all commercial fishermen (128 fatalities per 100,000 FTE) and all US workers (4 per 100,000 FTE).[6] The same review of US Coast Guard data[1] showed that many of the nonfatal injuries reported occurred when working with gear, particularly hauling the gear (pulling and handling the pots to harvest crab), and that most of the injuries (48%) affected the upper extremities. In a survey of injuries experienced by Dungeness crab fishermen during the 2014/15 season, 20% of Dungeness crab fishermen reported at least one injury in the previous fishing season and nearly 66% of the injuries reported were musculoskeletal injuries.[7] Where many previous studies in commercial fishing have focused on fatality prevention, musculoskeletal injuries have been understudied. Hence, the focus of this study is on risk of musculoskeletal injuries in the Dungeness crab fleet.

Previous studies showed the majority of these musculoskeletal injuries were associated with handling, hauling, and setting crab pots.[1,7–9] The fishermen's manual crab pot handling activities can pose well-known physical risk factors associated with musculoskeletal injury including forceful exertion (crab pots, when empty, can weigh more than 45.4 kg), repetition (multiple pots are on a "string" that is harvested in sequence), and awkward postures (reaching to land the crab pot on the sorting table). Despite these potential risk

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factors, there is no quantitative information available on the physical risk of commercial Dungeness crab harvesting. Therefore, there is a critical need for such objective risk information, which will provide a fundamental basis for developing injury prevention strategies for these commercial fishermen.

Previous ergonomics research in commercial fishing has been completed, but none with more recent technologies such as wearable inertial measurement unit (IMU) sensors that enable more objective and continuous risk assessment. Kucera et al.[10] video taped commercial fishing work using the Posture, Activity, Tools and Handling (PATH) and the Continuous Assessment of Back Stress (CABS) methods. Other previous studies used observational data and interviews to evaluate risk factors asociated with low back pain.[11,12]

While subjective and observational approaches are widely used in various workplace settings, it is challenging to use them in commercial fishing due to the working environment and schedule (e.g., multiple days at sea, limited researcher access to the vessel, and regulatory reasons). Moreover, the repeatability and reliability of subjective and observational methods are known to be inferior to objective assessments using scientific apparatus such as digital inclinometers, accelerometers, and inertial measurement unit (IMU) sensors.[13,14] Previous studies have shown these technologies can objectively quantify physical exposures in worker populations where subjective and observational approaches are not feasible.[15–17]

This study used IMU sensors to measure fishermen's work postures and related biomechanical injury risks during actual commercial Dungeness crab fishing, because observational exposure assessment was not possible. IMU sensors are generally equipped with a combination of accelerometers, gyroscopes, and magnetometers to measure linear acceleration (X, Y, Z) and angular velocity (pitch, roll, yaw) as well as orientation.[18,19] IMU sensors have increasingly been used to measure body posture, acceleration, and joint torque due to its various advantages including lightweight, small sizes, insensitivity to light and reflection, no restriction for space volume, self-contained memory, wireless capability, and low cost.[19–23] These advantages make the IMU sensors useful, especially when work is performed in a remote work setting.[18] On the other hand, IMU sensors also have some noteworthy limitations, including signal drift and sensitivities to magnetic fields. Therefore, IMU sensors should be used with caution in the environments where magnetic fields are not homogeneous or in the presence of metal.[24,25] Despite these limitations, previous studies and reviews consistently show that wearable IMU sensors can be useful assessment tools that provide reliable human movement data in a field setting.[17,18,26]

The objective of this study was to evaluate the feasibility of obtaining objective ergonomic assessments of Dungeness crab fishermen while at sea. This reports a field-based study using wearable IMU sensors to characterize the deckhand motions in crab harvesting tasks. In addition, we report the findings from structured interviews on the fishermen's work organization and the biomechanical load measures using the three-dimensional static strength prediction program based on commercial crab fishermen's anthropometry and crab pot mass.

Methods

This study consisted of three parts:

(1) A field-based study [N = 7] to determine the feasibility of using IMU sensors to objectively characterize working body postures, repetition, and duty cycle during regular commercial Dungeness crab fishing activities.
(2) A structured-interview study [N = 24] to collect fishermen's work organization, anthropometry, and grip strength that were used as input variables for the subsequent biomechanical analyses.
(3) Using the IMU sensor data (1) and the interview data (2), subsequent biomechanical analyses were performed to evaluate commercial Dungeness fishermen's musculoskeletal injury risk in the shoulders and low back region.

Participants

For the field-based IMU sensor feasibility study, seven commercial Dungeness Crab fishermen participated. The mean (SD) age, body mass, and height for the participating fishermen in the feasibility study were 35.4 (12.2) years, 79.5 (7.1) kg, and 177.8 (9.2) cm. For the structured interview, 24 commercial Dungeness Crab fishermen participated. The seven fishermen who participated in the field-based IMU study were recruited for the structured interview. All fishermen were recruited as a convenience sample through the support from local extension and commercial fishing community members in Oregon (Newport and Astoria) and Washington (Westport). Eligibility criteria included at least 18 years-of-age and commercial crab fishermen work with the Dungeness crab fleet. All the participants were male commercial Dungeness Crab fishermen and experienced deckhands who mainly performed crab harvesting and manual pot handling activities (the range of Dungeness crab fishing experience was between 2 and 30 years). All the study protocols were approved by the University's Institutional Review Board, and all of the participants provided signed consent prior to data collection.

Data collection and analysis

IMU sensor data

After obtaining written consent, our researchers administered a demographic and work questionnaire to collect age, gender, race, ethnicity, mass, height, job description, and fishing experience, all of which were self-reported. Before the fishermen left the harbor to fish, the designated researcher placed the three IMU wireless sensors (Biostamp nPoint; MC10; Lexington, MA) on the participants' torso (the midpoint of sternum) and the lateral aspects of the participants' left and right arms directly below the middle deltoid muscle (one-third of distance from acromion to the lateral epicondyle) (Figure 1). These specified placement locations and the designated researcher helped ensure the repeatability of consistent sensor placement across the participants. Before placing the sensor, the skin of the placement areas was shaved with a medical-grade razor and cleaned with alcohol swabs. Then, the sensors were secured by using waterproof double-sided tapes provided by the sensor manufacturer as well as breathable medical dressing film (Tegaderm, 3 M, Saint Paul, MN). After securing the sensors, the participants performed standardized postures (T-pose for 3 seconds, three torso flexions, and five arm abductions) to check the sensor placement and orientation. Data were saved in the sensors' self-contained memory to avoid any potential noise and data loss due to wireless data transmission. The use of IMU sensors has been validated and used to measure torso and arm postures during apple harvesting tasks in field settings.[17] When the fishermen returned to port, they returned the sensors directly to a research team member or mailed them to our research laboratory. The average sensor wearing time was 26 hours, ranging from 14 to 42 hours.

The wireless IMU sensors continuously collected raw acceleration of the arms and torso at a sample rate of 62.4 Hz during fishermen's regular work (Dungeness crab harvesting). These wireless IMU sensors have the internal clock used to continuously synchronize the data among the attached sensors, and save the collected data in its self-contained memory. Once data collection is completed, the collected data are wirelessly transmitted to a host computer and automatically saved into a cloud server for subsequent data processing and analysis. The accelerometers in the IMU sensors were set at a range of ± 8 g with precision of 0.6 mg. The raw data were processed and analyzed using a custom-built analysis software program (LabVIEW 2019; National Instruments; Austin; Texas, USA). Briefly, the raw data were filtered using a dual-pass 1-Hz low-pass Butterworth filter. By looking at the filtered acceleration data, we excluded idle time between harvesting activities in order to calculate the arm and torso angles during crab harvesting (Figure 2). This pattern is expected since the crab pots are connected on a string with 20 to 100 crab pots. Once the string is drawn to the vessel, the deckhands harvest

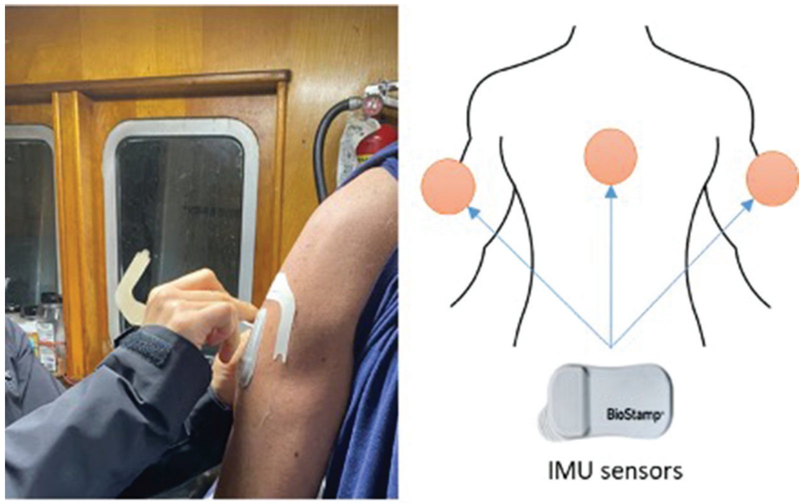

Figure 1. Placement of inertial measurement unit (IMU) sensors.

continuously, but take a break between the strings, while the vessel is moving to the next string. Using the idle (resting) and harvesting time, we calculated the work/rest cycles (harvesting/resting) by reviewing the patterns in the data.

In this study, arm and torso angles were calculated based on the linear acceleration data collected from the triaxial accelerometers of the IMU sensors.[17] Arm elevation angles (θ_{Arm}) of each arm were calculated based on the filtered acceleration. The vector sum ($\vec{v}$) of X (fore-aft) and Y (lateral) acceleration were computed. Then, the arm elevation angle was calculated by the arctangent of the vector sum ($\vec{v}$) divided by Z (vertical) acceleration as shown in Figure 3.[17] Using the filtered torso acceleration, torso flexion angle (θ_{torso}) was calculated as the arctangent of the Z (vertical) and X (fore-aft) acceleration (Figure 3). The posture angles were summarized using amplitude probability density function (APDF): 5th (min), 50th (central tendency), 95th (peak), and range of motion (95th–5th percentile).[17,27]

In addition, the percentage of time (% work time) was calculated for the following angle ranges: 0–30°, 30–60°, 60–90°, and greater than 90° for the torso and both arm angles. These angles were calculated only for the actual crab

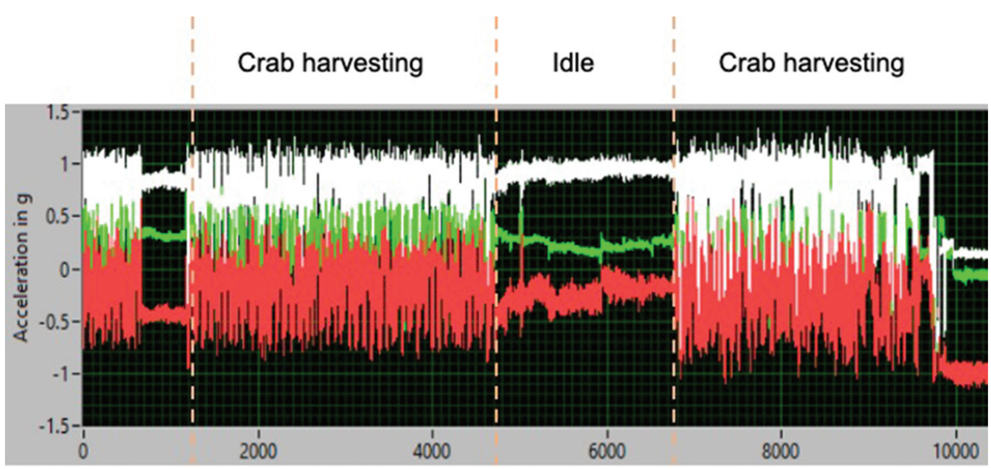

Figure 2. An example of a participant's typical acceleration data measured by inertial measurement unit (IMU) sensors showing duty cycles (crab harvesting and idle pattern).

harvesting tasks and the angles during idle time were excluded.

The repetitions of the arm and torso movements were calculated using local minima and maxima of the angle data.[18] A repetition was identified when a difference between successive minima and maxima was greater than 10°. To account for different work duration among the participants in different vessels, the repetition rate was calculated by dividing the total number of repetitions by the total measurement duration in minutes (repetition per minute).

Structured interview data

The structured interviews and measurements were conducted in person and recorded in a computer-based survey by study team members. We collected information about the fishermen's work organization (number of pots on a line, number of lines, typical steps and positions for harvesting crab) on their vessel with their setup. During the interviews, anthropometric data were collected via self-reported measures (height and body mass) and direct measures (arm length, shoulder height, elbow height, waist height, and knuckle height). The direct measures were collected from the dominant hand side of the body with flexible measuring tape while the fishermen were standing upright, clothed, and shoed. The arm length was determined by measuring from the acromion process to the knuckle of the middle finger with the arm outstretched forward and wrist straight. The shoulder height, waist height, and knuckle height were all measured with the fishermen looking straight ahead, shoulder's relaxed and arms at side, with the legs straight and feet flat on the floor with heels close together. Measuring the height from the floor to the acromion for the shoulder height, to the iliac crest for the waist height, and to the middle knuckle for the knuckle height. The elbow height was measured in a similar fashion, but the arms were bent 90° forward to measure the height at the olecranon. Fishermen's grip strength was measured using a hydraulic hand dynamometer (Jamar 5030J1; Patterson Medical, Warrenville, IL) while the elbow was flexed about 90° and the wrist was in neutral to slight ulnar deviation.[28] The highest value of three measurements was taken to represent each participant's grip strength. A 2-minute

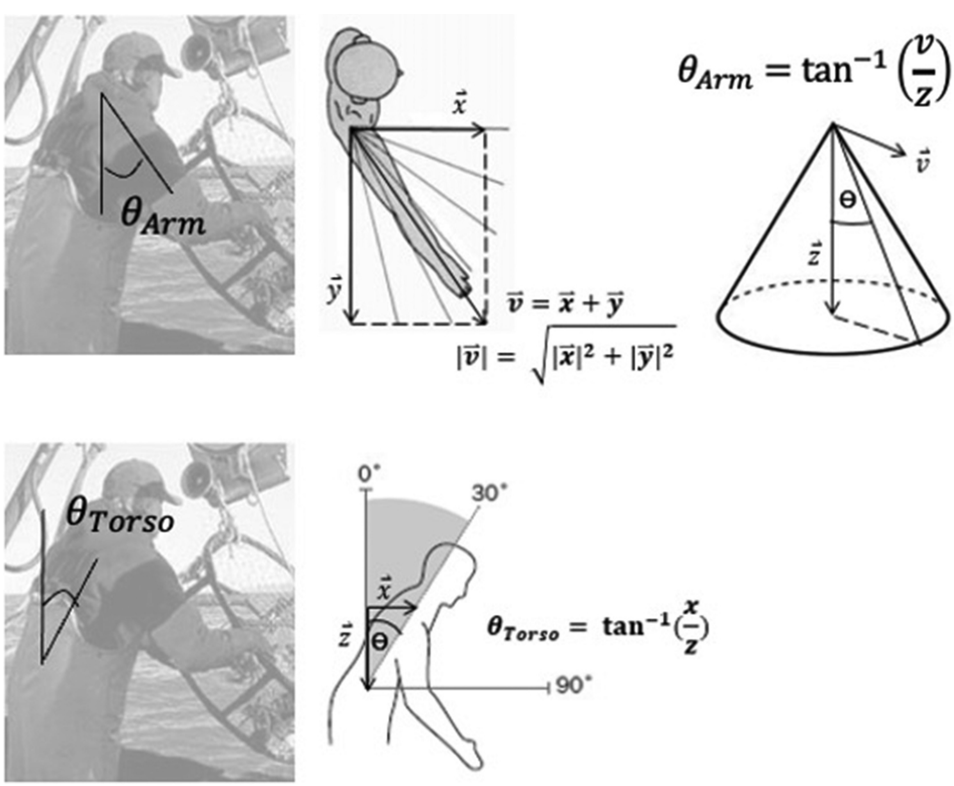

Figure 3. Inertial measurement unit sensor placements and postural angle calculation.

break was given to participants between the three trials. The crab pot weight and size were self-reported and confirmed with coastal equipment suppliers, captains, and vessel owners.

Descriptive statistics were used to summarize the reported work organization characteristics. A simple qualitative summary of the open-ended questions was possible since the questions were specific to standard work tasks of harvesting crab.

Biomechanical load analysis

Based on the collected crab pot mass, fishermen's anthropometry and posture during crab harvesting, the biomechanical load measures (force and moment) in the shoulders and low back were estimated using the 3-Dimensional Static Strength Prediction Program (3DSSPP). We used the anthropometric data collected from the 24 commercial fishermen to represent Dungeness crab fishermen in estimating the biomechanical load measures. As the IMU sensor data provided only the arm and torso angles, the elbow angles were set such that the hands/wrist were between the waist (Mean ± SD: 107 ± 6.3 cm) and knuckle height (82 ± 7.3 cm) based on the participants' anthropometry measures (Figure 4). The wrist angles were set as neutral and parallel to the forearm angles. The lower extremity angles were fixed as neutral. The hand load was determined based on the average crab pot mass (51.7 kg, ranging from 31.8 to 90.7 kg) and evenly distributed between the hands. Because the crab pot handling is typically a two-person job, the hand load was half of the pot's mass: 7.9 (min), 12.9 (average), and 22.7 (max) kg. Based on these input variables, the low back forces (compression and shear) and flexion moment at the low back (L5/S1) and the shoulder joint were calculated based on 10th, 50th, 90th percentile values of the arm and torso angles.

Results

Postures while harvesting crab

The average measurement time during crab harvesting was 26 hours, ranging from 14 to 42 hours. The data showed the average idle time (non-harvesting) was 60% of the total measurement duration. The following results are based on the data collected for the average active harvesting duration of 10 hours, ranging 2.4 to 17 hours. The results showed that the median torso flexion angle was approximately 17° (Table 1). The

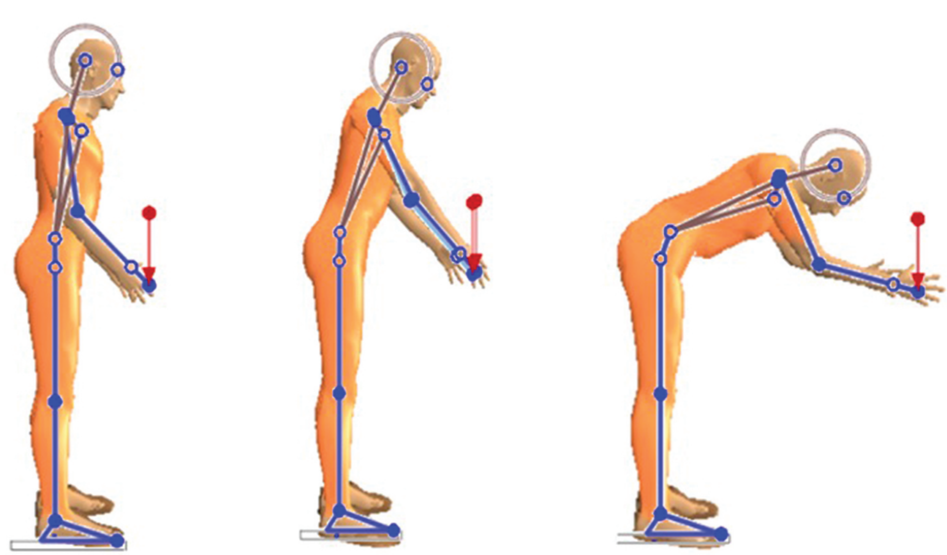

Figure 4. An example of 3DSSPP models with the 10th (left), 50th (middle), 90th (right) percentile of torso flexion angles. The hand/wrist location was set such that the hands/wrist were set between the waist and knuckle height. The lower extremity angles were fixed as neutral.

fishermen spent ~22% on average (SD: 2.8%) of their crab harvesting activities with the torso flexion greater than 30°, which is known to be associated with back disorders (Figure 5). The arm elevation angles were about 27° and relatively symmetric between the arms. The participants spent ~10% on average (SD: 2.7%) of their time with arm elevation greater than 60° (Figure 5), which increases the risk for musculoskeletal disorders.

Dungeness crab fishermen's work organization and anthropometry

The interview results showed that crab pot sizes (diameter) ranged between 96.5 and 107.7 cm with the average weight of 51.7 kg (ranging from 31.8 to 90.7 kg). Depending on the weather, time of season, number of crew, and size of vessel they could pull between 100 and 500 pots per day. The crew sizes ranged from two to four deckhands with one captain. Fishermen reported there could be more deckhands in a crew early in the season when the fishing is more intense. The deckhand duties include operating the block, pulling and landing the pot, taking the crab from the pot, sorting and measuring the crab, handling and preparing bait, and for some, being the deck boss. The anthropometry and grip strength data of these 24 commercial fishermen are summarized in Table 2.

Table 1. Postures, range of motion (ROM), and repetition of torso and arms.

	Median posture (degrees) [5th, 95th percentile]	Range of motion (degrees) [95th–5th percentile]	Mean repetition rate (repetitions/ minute) [SD]
Torso	16.9 [5.3, 56.5]	51.1	12.1 [5.5]
Right arm	26.7 [8.3, 64.5]	56.2	16.7 [5.5]
Left arm	27.2 [7.9, 72.2]	64.3	16.2 [5.6]

Estimated biomechanical loading

The biomechanical loading in the upper extremities and low back was estimated using 3DSSPP. The force and flexion (-) moment were calculated based on 10th, 50th, 90th percentile values of the arm and torso angles with the average crab pot mass (51.7 kg); the values in the brackets represent the force and flexion moment with the minimum (31.8 kg) and maximum crab pot mass (90.7 kg), respectively. The estimated low back compression and shear force and flexion moment about shoulders and L5/S1 are summarized in Table 3.

Discussion

The present study demonstrated the feasibility of using inertial measurement unit (IMU) sensors to objectively characterize biomechanical exposures (e.g., postures, repetition, and duty cycle) during fishermen's regular work shift. In addition, based on the collected IMU sensor data, fishermen's

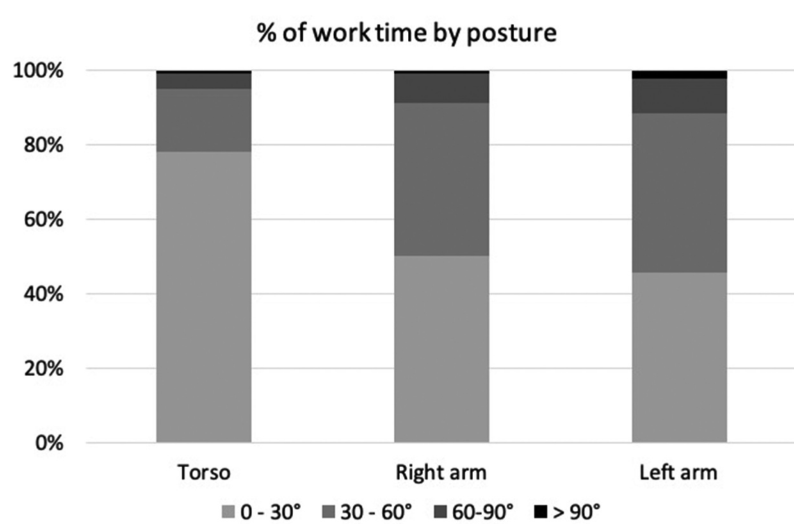

Figure 5. Mean percentage of time spent in different posture ranges of the torso, right and left arms: 0–30°, 30–60°, 60–90°, > 90°.

Table 2. Mean (SD) anthropometric and grip strength data collected from 24 commercial Dungeness crab fishermen.

Measurement	Mean (SD)
Height (cm)	180.1 (5.7)
Body mass (kg)	93.2 (20.8)
Arm length (cm)	76.6 (4.0)
Shoulder height (cm)	148.2 (5.3)
Elbow height (cm)	115.1 (5.1)
Waist height (cm)	107.0 (6.3)
Knuckle height (cm)	81.6 (7.2)
Grip strength right (N)	595.3 (70.1)
Grip strength left (N)	567.2 (100.8)

work characteristics (pot weight) and anthropometric data, biomechanical analyses were performed to evaluate commercial Dungeness fishermen's musculoskeletal injury risks in the shoulders and low back regions. The results demonstrate further investigation and field measures could inform musculoskeletal injury prevention strategies.

Through engagement with fishermen at training sessions and local meetings, we collected information about their work organization and anthropometric measures. In addition, we successfully recruited fishermen for the feasibility study by bringing the wearable sensors to these events for fishermen to "try on" and learn about what information could be obtained. We were able to coordinate with fishermen and their fishing schedules to place the IMU sensors before a fishing trip. We had 100% compliance from fishermen to keep the sensors in place for several harvesting work cycles (14–42 hours of data collection) and return the sensors once back at port.

With this valuable information, we learned about commercial Dungeness crab fishermen's work organization when harvesting crab, and about their risk of low back and shoulder injury due to harvesting. From reviews of US Coast Guard reported and survey reported injuries in the Dungeness crab fleet, we know that the most frequent injuries are sprains and strains to the upper extremities and are due to hauling pots.[1,7] From the interviews in this study, we understand that the deckhands are harvesting pots in a continuous cycle when a line is being pulled, but then complete other tasks or rest when the vessel is moving to a new line or is moving to the fishing site from the port. We were able to estimate the work/rest cycles (40% harvesting/60% rest/not harvesting) by reviewing the patterns in the data. Providing fishermen with the information of the postural and repetitive motion risks while they are actively harvesting, can help promote the importance of resting and that they should include neutral postures.

The overall study's goal is to inform fishermen, with objective measures, about the physical risk associated with harvesting crab. The posture and repetition data collected by IMU sensors demonstrated that harvesting crab can pose risk for low back and shoulder injuries over time. The results showed that about a quarter of the harvesting time was spent with the fishermen's backs flexed greater than 30°. Research shows that moderate levels of back flexion (21–45%) can increase back injury risk four- to sixfold if experienced regularly over time.[29] Moreover, the repetition of back flexion was relatively high (12 flexions per minute) during the work cycles. Given the heavy crab pot mass (up to 91 kg), the back postures and repetition rate, the crab harvesting task may pose significant back injury risk since risk is substantially increased when multiple risk factors exist (forceful exertion, awkward postures, repetitive motion).[29–32]

The estimated compression and shear forces of the spine associated with harvesting crab may also indicate potential risk of back injury. Many previous studies as well as NIOSH recommendations consistently suggest that the compression of 3400 N or higher significantly increases the risk

Table 3. Biomechanical load measures estimated by three-dimensional static strength prediction program (3DSSPP).

		Percentiles		
		10th	50th	90th
Low back force (N)	Compression	2202 [1699–3088]	3051 [2371–4415]	5044 [3968–7748]
	Shear	466 [404–588]	469 [406–591]	637 [552–804]
Flexion (-) moment (Nm)	Shoulder	41.2 [26.9–69.2]	59.7 [39.8–93.6]	99.2 [66.6–162.9]
	L5/S1	110.1 [78.2–172.8]	184.1 [130.2–289.6]	380.2 [303.7–503.1]

The force and flexion (-) moment were calculated based on 10th, 50th, and 90th percentile values of the arm and torso angles with the average crab pot mass (51.7 kg); the values in the brackets represent the force and flexion moment with the minimum (31.8) and maximum crab pot mass (90.7 kg), respectively.

of back injuries.[33–35] With the 50th percentile measures around 3051 N and then 5044 N for the 90th percentile for the fishermen, the recommended limit for compressive force is likely exceeded during the harvesting tasks. The heavy load of handling a crab pot full of live crab with awkward postures (i.e., back flexion) is contributing to this compressive force. Moreover, the shear forces estimated (10th–90th percentile: 466–637 N) were below a well-known maximum permissible limit of 1000 N for single exertions (34) but potentially above an action limit of 500 N for repeated exertions.[36,37] As the Dungeness crab fishing tasks are repetitive, the shear force during the crab harvesting is also a potential risk for low back injuries. As shown in Table 3, the flexion moment at the low back during the Dungeness crab fishing was considerably high (up to 390 N m for the 90th percentile). Previous studies have shown that the low back moment of 200 and 315 N m is associated with the back compressive force of 3400 (NIOSH action limit) and 6400 N (NIOSH maximum permissible limit), respectively.[38,39]

From the interviews, fishermen described using both arms to handle the crab pot. Our summary findings demonstrated that the right and left arm motions were relatively symmetrical. The arm elevation angles (i.e., shoulder flexion) ranged from approximately 8° to 70°, and the fishermen spent ~10% of their time with arm elevation greater than 60°. Shoulder flexion of 60° or higher is known to significantly increase risk for shoulder injuries.[30] A previous study showed that severe shoulder flexion for 10% of the job cycle can increase injury risk two- to threefold.[40] While the fishermen spent a fraction of their harvesting time with high shoulder flexion, such awkward shoulder postures along with the substantial range of motion (~60°) and high repetition rates (16 times per minutes) can increase risk for shoulder discomfort and injuries. However, since the fishermen did have idle time (not used in our estimates), this risk would be reduced. If the fishermen have prolonged periods of harvesting during the heaviest fishing part of season, this could put them at a higher risk of developing shoulder disorders. Additionally, the estimated shoulder flexion moment (41 and 99 N m for the 10th–90th percentile, respectively) was considerably higher as compared to the moment estimated for other highly demanding tasks such as patient handling.[41] A previous study showed that the shoulder moment associated with male's maximum shoulder strength capability ranged from 45 to 80 N m.[42] Previous studies have also shown that shoulder moment exceeding strength capability can increase risk for shoulder disorders.[43,44] The considerably high shoulder moment indicates that Dungeness crab fishing may pose risks for shoulder discomfort and injuries.

These biomechanical analysis results indicate that there is a critical need to develop interventions to mitigate potential high risk for low back and shoulder injuries among the Dungeness crab fishermen. Fishermen have already developed engineering and administrative controls appropriate to help reduce the risk of musculoskeletal injuries. The addition of a banger bar, which is a frame added on top of a sorting table to bang the pot against, to reduce the torso flexion and upper extremity motion is one example. We are currently evaluating different designs of this banger bar to provide scientific evidences (its advantages and limitations) to the Dungeness crab fishermen. Related to the addition of the banger bar, is the sorting table height. Our field survey on commercial Dungeness crab fishing vessels found that the average crab sorting table surface height was 16 inches, which was significantly lower than the NIOSH-recommended work surface heights.[45] Given the average elbow height (45.3 ± 2 inches) of our study's fishermen, we found that such a low sorting table height could result in significant biomechanical load in the low back. Our ongoing study is currently evaluating the effects of the sorting table heights and banger bars on the musculoskeletal stress in the low back and shoulders. For administrative controls, the fishermen are able to take breaks between lines and in transit so ensuring those can promote work/rest cycles that allow for recovery is possible.

While this study showed feasibility of using the IMU sensors, it has some limitations. First, due to the small sample size, the representativeness and generalizability of the study results may be limited. Second, this study did not account for the potential effects of vessel motion on biomechanical loading measures as the acceleration was not measured from the vessel. As a previous study showed that ship motion can increase joint torque (up to 5%) and compression (up to 10%),[46] the biomechanical loading measures may have been underestimated. Therefore, it will be important to measure the ship motion (i.e., acceleration) to account for its potential effects on the biomechanical loading in future studies. Lastly, IMU sensors are susceptible to errors including signal drift and sensitivities to magnetic fields. To avoid such errors, arm and torso angles were calculated using the linear acceleration data collected from the triaxial accelerometers of the IMU sensors without converting the acceleration to position data, which is a source for computation errors and signal drift. Because the accelerometers are independent of magnetic fields, acceleration-based posture calculations can provide more robust angle estimation by minimizing potential drift-induced errors. Despite these limitations, since the intent was to determine if the fishermen, who can be wary of health and safety research, would allow any kind of assessment and if wearable IMU sensors could be used for such an exposure assessment, this was a success. This less-invasive objective risk assessment approach using IMU sensors will allow research and commercial fishing community to obtain injury risk data more easily. Consequently, readily available risk information can be used to establish the exposure–response relations between musculoskeletal injuries and physical risk measures in the future studies. Moreover, IMU-based risk assessment will allow objective evaluations of an intervention on vessels in a real, field setting when needed.

Conclusion

This study demonstrates that the use of biomechanical and objective information can be used to characterize physical risk of commercial fishermen. The risk estimated in this study indicates that the commercial Dungeness crab fishermen may be at risk for shoulder and back musculoskeletal injuries. Prevention efforts to improve the ergonomics of fishing tasks (e.g., redesigning working environment such as using banger bars, adjusting the sorting table surface height, promoting appropriate work/rest cycles) are paramount to reduce this risk. Finally, these methods can be applied to assess risk in a larger study and with different vessel and equipment configurations.

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Disclosure statement

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