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Effects of different sorting table heights on low back and shoulders biomechanical loads during dungeness crab sorting

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Abstract

West Coast Dungeness crab fishers suffer a high prevalence of musculoskeletal injuries, especially low back pain. Substantial trunk flexion and associated low back loads during crab sorting tasks have been attributed to awkward sorting table heights. This study examined how varying table heights affect biomechanical loads on the low back and shoulders. Twenty-five participants performed crab sorting tasks at three table heights while trunk and shoulder joint angles, moments, muscle activity, perceived exertion, and discomfort were measured. Increasing table height reduced trunk flexion and lumbosacral (L5/S1) joint moments but increased shoulder flexion moments and upper trapezius muscle activity. Table height did not affect perceived exertion or discomfort. These findings indicate that increasing sorting table height can reduce biomechanical load on the low back but results in increased shoulder strain. This trade-off underscores the importance of adopting ergonomic designs balancing low back and shoulder biomechanics to determine appropriate sorting table height.

Keywords

Commercial fishing; Musculoskeletal disorders; Electromyography; 3-D motion capture

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

1. Introduction

Commercial fishing is a high-risk and physically demanding occupation. Existing epidemiologic evidence consistently shows that commercial fishers suffer from a high rate of non-fatal injuries, especially work-related musculoskeletal disorders (WMSDs). A systematic literature review of 13 observational studies reported that WMSDs are highly prevalent among fishermen worldwide, ranging from 15 % in England to 93 % in Egypt (Remmen et al., 2021). This review showed that the back regions, particularly the lower back, were the most affected body parts, with shoulders and knees also being affected. In the U.S., a cohort study in North Carolina reported an 83 % prevalence rate of musculoskeletal complaints among fishers, with lower back pain being the most frequent at 52 % (Lipscomb et al., 2004). Similarly, a study in the Northeastern U. S. found that approximately 82 % of surveyed lobstermen reported pain, with lower back pain being the predominant complaint at 50 % (Fulmer et al., 2017).

West Coast Dungeness crab fishers experience a high prevalence of non-fatal injuries, with one in five reporting an injury over a one-year period (Bovbjerg et al., 2019). A recent study showed that activities performed on deck, including handling and hauling fishing gear and crab sorting, were among the most common factors associated with injuries among Dungeness crab fishers (Kincl et al., 2023). Dungeness crab harvesting involves pulling crab pots strung on ropes from the water onto the vessel's deck, with each rope containing more than 50 pots that are pulled up continuously until the end of the rope. These crab pots are emptied onto a sorting table (or dump box) where crab is sorted by gender and size, with female and undersized crabs returned to the sea to maintain a sustainable fishery. Crab sorting during the harvest may pose various physical risk factors associated with WMSDs, including awkward postures and repetitive motions, and has been associated with an increased rate of low back pain among commercial fishers (Kucera et al., 2009).

Previous studies have shown that this association may be attributed to the nonergonomic design of crab sorting tables, with surface heights that often fall below the recommended work surface heights (Imaekhai, 2018; Kucera et al., 2008). Our previous survey of crab fishing vessels in the West Coast fleet further confirmed the improper design of sorting tables used in crab harvesting, with an average surface height as low as approximately 40 cm (Kim et al., 2023). This low surface height forces severe trunk flexion and increases biomechanical load in the low back during crab sorting, thereby elevating the risk of low back injuries and pain among commercial crab fishers.

Previous studies have explored the effects of some ergonomic interventions in reducing the physical strain among commercial crab fishers, such as crab pot boom and ramp systems (Mirka et al., 2011) and adding a banger bar for emptying crab pots (Kia et al., 2023). However, there is a lack of studies focusing on the impacts of crab sorting table heights on biomechanical loads experienced by Dungeness crab fishers during sorting operations. To fill this gap, this study aimed to quantify both objective (joint angles, moments, and muscle activity) and subjective (perceived exertion and discomfort) biomechanical metrics in the low back and shoulders during crab sorting tasks at various work surface heights. In addition, this study aimed to identify critical, evidence-based design recommendations for

sorting table heights to reduce the risk of musculoskeletal injuries among Dungeness crab fishers.

2. Methods

2.1. Participants

A total of twenty-five healthy males participated in this laboratory-based study. All participants were exclusively male and older than 21 to represent the West Coast Dungeness crab fishers' population (Kincl et al., 2023). Participants were recruited through online (e.g., email and social media) solicitation and printed flyers distributed throughout the Oregon State University community in Corvallis, OR. The inclusion criteria for participants included: 1) no restriction in physical activity; 2) no current musculoskeletal pain (past 7 days) in the upper extremity and lower back regions; and 3) no ongoing medication use for musculoskeletal disorders to avoid the potential risk of injury among participants during experimental tasks. Table 1 presents descriptive information regarding the participants' demographic and anthropometric characteristics.

2.2. Experimental setup

For this study, a crab sorting table with a length of 153 cm and a width of 92 cm was custom-built by a coastal vessel equipment fabricator (Fig. 1). These specific dimensions were selected based on our field survey of commercial Dungeness crab fishing vessels (Kim et al., 2023). The table was designed to be height-adjustable to investigate the impact of different work surface heights, including low, medium, and high, on low back and shoulder biomechanical loads. The low setting corresponds to the average surface height of the sorting tables currently used by the West Coast Dungeness crab fishermen (~40 cm). The high setting was determined such that the top of the raised edge was around the average elbow height of commercial fishers collected in our previous field study (Kim et al., 2023), which set the work surface height at 56 cm (Fig. 1). Although this 'high' condition is still well below the recommended work surface height for standing tasks (86–94 cm), this height was set as the highest condition as the sorting table function and the overall crab fishing process prevent further elevation. Briefly, before sorting crab, fishers land heavy crab pots (typically 100 kg) on the top of the raised table edge to empty the pots. Given the 40-cm raised edge of the sorting table to contain sufficient catch for sorting (Fig. 1), further raising the overall table height can create substantial physical stress and risks due to increased shoulder flexion and low back extension during crab pot handling. Lastly, the medium setting is the midpoint between low and high settings. Artificial plastic crabs, with a size of 14 × 17 cm and a mass of 150 g, were used to simulate the sorting task performed during Dungeness crab fishing. To represent characteristics of actual crab sorting tasks, two distinct colors of plastic crab (i.e., blue and red) were used for participants to distinguish and sort them by color.

2.3. Experimental protocol

Prior to the experiment, the study's objectives, procedures, and potential risks were explained to participants, and written consent forms were obtained. Afterward, participants were outfitted with a conventional full-body marker set and electromyography (EMG)

electrodes (Fig. 2). Markers and electrodes were attached to the participants using double-sided tapes and secured by over-taping to avoid potential displacement during the experiment. Maximum voluntary contractions for each muscle were measured before the main experiment. Following that, participants practiced the task until they felt confident about performing the requested task (5–10 min). The experiment involved performing a simulated crab sorting task on a sorting table with various heights (Fig. 3) and at a self-selected pace (the average time to complete the sorting task was 71 s). The task involved sorting 40 crabs by color at three different storing table heights mentioned. The order of the sorting table heights was randomized and counterbalanced using a random number generator (R 4.3.1) to minimize potential confounding effects due to the order of the experiment. In addition, a 5-min break was given between sorting tasks to avoid the effects of residual fatigue from the previous task. The total duration of sorting tasks per participant took approximately 15 min given the average task duration of 71 s per table height with the 5-min breaks between the height conditions. During the experiment, we measured joint kinematics using an optical motion capture system and muscle activity using EMG. In addition, we collected subjective metrics, including self-reported discomfort and perceived exertion, before and after each experimental condition (different table heights). The protocol for this study was approved by the Oregon State University Ethics Board (IRB-2019-0318).

2.4. Outcome measures

2.4.1. Angle and moment: Joint angles and corresponding moments about the low back and shoulders were measured during the tasks using kinematic data collected by a three-dimensional (3-D) optical motion capture system (Flex 13; Optitrack; Natural Point, OR). A total of 39 reflective markers were placed on the head, upper and lower arms, hands, trunk, pelvis, upper and lower legs, and feet of participants based on the full-body marker set from an optical motion capture software program (Motive 2.0; Optitrack; Natural Point, OR). The positions of the markers during the sorting tasks were collected at a sample rate of 200 frames per second using an 8-camera optical motion capture system (Flex 13; Optitrack; Natural Point, OR). After data cleaning and gap-filling, raw kinematic data were filtered by a digital zero-phase fourth-order Butterworth filter with a cutoff frequency of 6 Hz (Motive 2.0; Optitrack; Natural Point, OR).

Trunk and shoulder flexion angles were calculated by processing the filtered kinematic data using Visual3D (C-Motion Inc., Germantown, MD). Trunk and upper arm segment coordinate systems were defined as follows: the X-axis was directed toward the participant's right side (mediolateral axis), the Y-axis was directed forward (anterior-posterior axis), and the Z-axis was directed longitudinally upward (inferior-superior axis). The Euler angle sequence of X-Y-Z was applied for the angle calculations. Trunk flexion angles were derived from the rotation matrices of the trunk relative to the global coordinate system (X-axis). The shoulder flexion angles were calculated from the rotation matrices of the upper arm relative to the trunk (X-axis). The lumbosacral joint (L5/S1) and shoulder flexion moments were computed using a 3D dynamic multi-segment model (Kia et al., 2023; Kingma et al., 1996). A top-down approach was used to calculate moments based on body segment inertial parameters estimated using a regression model (de Leva, 1996) and their respective moment

arms estimated from kinematic data (Faber et al., 2020). Subsequently, the group means of the 5th, 50th, and 95th percentiles of angles and moments were calculated.

2.4.2. Muscle activity: Muscle activities were measured at 1000 Hz using a 16-channel wireless data logger (Trigno Avanti; Delsys; Natick, MA). Four surface electrodes were placed bilaterally on participants to collect muscle activity from the upper trapezius and lumbar erector spinae. The electrode sites were identified according to the European Recommendation for Surface Electromyography (Hermens et al., 2000). The electrode places were shaved and cleaned with alcohol pads (Marras, 1990).

The raw Electromyography (EMG) data was filtered using a bandpass filter of 20–400 Hz, rectified, and averaged using a 125-ms moving window to calculate root mean square (RMS) values (EMGworks; Delsys; Natick, MA). To normalize muscle activity, maximum voluntary contractions (MVCs) were collected before the experiment and based on procedures described in previous studies (Boettcher et al., 2008; Marras and Mirka, 1993; Roman-Liu and Bartuzi, 2018). Three MVCs were collected for each muscle, with a 2-min break between trials (Soderberg and Knutson, 2000). EMG values were normalized using the highest RMS signal over a 1-s period of the MVC contractions and reported as the percentage of the MVCs (%MVC). The normalized data was then summarized by the 10th (static), 50th (median), and 90th percentile (peak) muscle activities based on the Amplitude Probability Density Function (APDF) (Jonsson, 1978).

2.4.3. Subjective measures: Whole-body and localized perceived exertion in the lower back and shoulders were measured after each condition. Borg's rating of perceived exertion (RPE) scale was used to quantify the whole-body exertion on a scale of 6 (no exertion) to 20 (maximal exertion) (Borg, 1970). Localized perceived exertion was collected using the Borg category ratio (CR-10) on a scale of 0 (no exertion) to 10 (maximal exertion) (Borg, 1982). In addition, shoulder and low back discomfort were measured before and after performing the tasks using the Borg CR-10 (Borg, 1982).

2.5. Statistical analysis

Dependent variables (outcome variables) were joint angle/moment, muscle activity, perceived whole-body and localized exertion, and discomfort. Generalized linear mixed models (GLMM) were used to determine the effects of the different table heights on the dependent variables. The fixed effect (independent variable) was sorting table height (3 levels: low, medium, and high). Random intercepts were introduced to account for within-subject correlations. All dependent variables exhibited a normal distribution, except for the muscle activity data, which was log-transformed. An alpha (Type I) error of 0.05 was used as a statistical significance threshold. Any statistical significance was followed up with Tukey's HSD post-hoc tests. The R programming language (R 4.3.1, R Core Team; Vienna, Austria) was used for the statistical analysis.

3. Results

3.1. Joint angle and moment

The results showed that crab sorting tasks at the low table height (the average table height on current vessels) posed substantial trunk flexion (70.1°) and associated L5/S1 moment (98.0 Nm), as shown in Fig. 4. The trunk flexion and L5/S1 flexion moment significantly decreased as table height increased ($p < 0.001$). The post-hoc comparisons showed that the differences in trunk flexion and L5/S1 flexion moment between the pairs of the low, medium, and high table height conditions were statistically significant.

Similarly, the sorting table height had substantial impacts on shoulder flexion angles and moments during the crab sorting (Fig. 5). Both left and right shoulder flexion angles significantly decreased as table height increased from low to high ($p < 0.001$). The post-hoc comparison revealed that the 5th and 95th percentile left shoulder flexion angles only showed significant differences between the low and medium, and between low and high conditions. However, the 50th percentile left shoulder angles, as well as all percentiles of the right shoulder flexion angles, exhibited significant differences across all pairs of the low, medium, and high conditions. Conversely, shoulder moments followed the opposite trend, significantly increasing as table height increased ($p < 0.001$).

3.2. Muscle activity

The erector spinae (low back extensor) muscle activity showed a consistent trend of increased muscle activity with higher table heights, although the level of statistical significance varied (Fig. 6). For the left erector spinae, there were significant differences between table heights at the 10th, 50th, and 90th percentiles ($p < 0.025$). The 10th and 50th percentile muscle activities were significantly higher at the high table height compared to both low and medium heights ($p = 0.002$ and $p = 0.005$, respectively). At the 90th percentile, the high table height condition only exhibited significantly higher activity than the low height condition ($p = 0.025$). For the right erector spinae, the effects of table height on muscle activity did not reach statistical significance.

The upper trapezius muscle activity also demonstrated a consistent trend of increased activity with higher table heights (Fig. 7). On the left side, muscle activity significantly increased at the 50th and 90th percentiles, with the high table height showing significantly greater activity than the low table height at both percentiles ($p = 0.003$ and $p = 0.001$, respectively). There were no significant differences at the 10th percentile. On the right side, a similar trend was observed. Muscle activity significantly increased at the 50th and 90th percentiles, where the high table height showed significantly greater activity compared to the low table height ($p = 0.028$ and $p = 0.045$, respectively). No significant differences were found in the 10th percentile.

3.3. Perceived exertion and discomfort

Perceived whole-body and localized exertions and self-reported discomfort did not significantly differ across the three table heights during the crab sorting task (Table 2). Shoulder and low back discomfort ratings increased slightly from pre-to post-task, but these

changes were not affected by table height. There was no interaction effect between table height and time.

4. Discussion

The objective of this study was to evaluate the effects of crab sorting table heights on the biomechanical loads (joint angles, moments, and muscle activity) on the low back and shoulders during crab sorting tasks. The results indicate that adjusting the sorting table height can help decrease lower back strain but may simultaneously increase the burden on the shoulders. This trade-off highlights the importance of an ergonomic design that carefully balances trunk and shoulder mechanics to determine the optimal table height and reduce the risk of musculoskeletal injuries in commercial crab fishers.

4.1. Trunk angle and L5/S1 moment

Our findings showed that crab sorting tasks performed at the low table height (the average sorting table height of the current vessel settings found in the field) resulted in substantial trunk flexion angles (median angle = 70.1°) compared to the medium (median angle = 61.4°) and high (median angle = 50.0°) table height conditions. Previous studies have indicated that moderate (21–45°) and severe (over 45°) trunk forward flexion angles are strongly associated with a higher risk of back musculoskeletal disorders (Punnett et al., 1991). This association is due to the increased compressive and shear forces exerted on the lumbar spine at higher degrees of trunk flexion, which can lead to degeneration and injury of spinal structures over time (Gallagher and Marras, 2012; Gallagher et al., 2005). Consequently, this may explain the increased occurrence rate of low back pain associated with sorting catch on the boat, which can pose awkward static postures (Kucera et al., 2009).

The reduction in trunk flexion with higher table heights was in line with reduced L5/S1 moments: from 98.0 Nm at the low table height to 78.6 Nm at the high table height. The decreased trunk flexion angles could have reduced the horizontal moment arm between the torso's center of mass and the L5/S1 joint (center of rotation) and consequently lowered the L5/S1 joint moment. Previous studies have reported that proper workstation height can substantially reduce the biomechanical loads on the lower back (Marras et al., 1995; Hoozemans et al., 2008; Nelson et al., 2003; Larson et al., 2022). Lower L5/S1 moments imply less biomechanical loading on the lumbar spine, thereby reducing the risk of low back injuries (Granata and Marras, 1995; Marras et al., 1995; Norman et al., 1998). These findings corroborate a previous study showing that sorting tasks in upright postures was not associated with low back pain (Kucera et al., 2009).

Previous studies have shown that low back injury risk significantly increases when the L5/S1 moment exceeds 200 Nm, which is associated with an L5/S1 compressive force of 3400 N (the National Institute for Occupational Safety and Health (NIOSH) action limit) (Arjmand et al., 2015; Waters et al., 1993; Gallagher et al., 2009). In this study, the L5/S1 moments observed during crab sorting tasks (up to 105 Nm) were below this threshold, suggesting that the tasks may not pose substantial injury risks to the low back regions under the controlled laboratory conditions. However, as the simulated crab sorting tasks were performed with plastic crab whose mass (150 g) is substantially lighter than actual

Dungeness crab, the low back moment is likely to be much higher during actual crab sorting tasks. Moreover, the L5/S1 moments recorded were comparable to those associated with manual patient handling tasks (Jäger et al., 2013), which are known to pose significant injury risks among healthcare workers. Therefore, the crab sorting task may still pose considerable low back load and injury risks in real-world fishing environments.

4.2. Shoulder angle and moment

Shoulder flexion angles (median angle $>72.5^\circ$) during the crab sorting tasks were substantial regardless of table height. This is particularly concerning as previous studies have shown that shoulder flexion of 60° or greater can significantly increase risks for shoulder injuries (Bernard et al., 1997; Silverstein et al., 2008). As previous studies have observed a high prevalence of upper extremity injuries in the crab fishing industry associated with handling fishing gear (Case et al., 2015; FLIPP, 2017; Kincl et al., 2019), these substantial shoulder flexion angles during sorting tasks could also contribute to the risk of injury. Notably, shoulder flexion angles decreased as the sorting table height increased. The high sorting table may have reduced shoulder flexion because it allowed the participants to keep the crab close to the body, with the median shoulder flexion angle decreasing from 82.6° at the low height to 72.5° at the high height.

In contrast, shoulder flexion moments increased with higher sorting table heights. The increased shoulder flexion moment at higher heights may be attributed to the greater distance between the shoulder joint's center of rotation and the arm's center of mass. In the low setting, trunk flexion allowed the center of rotation and the center of mass to remain relatively aligned, minimizing the moment arm. However, when participants reached out to sort crabs farther from their bodies in a more upright trunk posture at higher table heights, the moment arm increased. Although the difference in shoulder flexion moment between low and high table height conditions was about 1.5 Nm in this study, which is relatively small, it is important to consider the field environment. For example, the average weight of Dungeness crabs is approximately 1 kg (10 times greater than the plastic crab used in this study), and the sorting tasks involve repetitive arm movements over prolonged periods. The heavier crab mass along with repetitive motions for prolonged periods can create cumulative effects and, therefore, amplify the impact of even small increases in shoulder moments. This increased shoulder moment could result in a higher load on the shoulder muscle, potentially causing muscle fatigue and discomfort during prolonged sorting tasks. Additionally, this finding aligns with the observed increase in upper trapezius muscle activity at higher table heights.

Previous studies on the effect of working height on low back and shoulder loading have found that the low back and shoulder experienced opposite effects during height changes (Faber et al., 2009; Gagnon et al., 1992; Jakob et al., 2012). While higher tables are beneficial for reducing trunk flexion, they must be carefully designed to manage the shoulder moments and avoid overloading the shoulder musculature. This trade-off highlights the need for a balanced approach in ergonomic design that considers both trunk and shoulder biomechanics to optimize sorting table height and reduce the risk of musculoskeletal injuries among commercial crab fishers.

4.3. Muscle activity

The erector spinae muscle activity increased as the sorting table height increased, which contradicts the reduced low back moment. While this appears to be counterintuitive, the lower erector spinae muscle activity with increased trunk flexion might be attributed to the flexion-relaxation phenomenon (FRP). The FRP describes a marked reduction in erector spinae muscle activity during forward trunk flexion, typically occurring between 50 and 70 degrees of flexion (Colloca and Hinrichs, 2005; McGill and Kippers, 1994). This phenomenon indicates a transfer of load from the active muscles to the non-contractile connective tissue, such as tendons and ligaments. The increased strain on connective tissues is known to be associated with low back pain and related disorders (Granata et al., 2005; Shin and Mirka, 2007; Solomonow et al., 2003). Therefore, the reduced muscle activity in the erector spinae indicates that biomechanical load associated with the increased low back moment observed in the low table height may have transferred to non-contractile connective tissues.

The muscle activity in the left erector spinae was significantly larger than the right across all height conditions. This asymmetry might be attributed to hand dominance, as our collected demographic data indicated that 22 out of 25 participants were right-handed. The right side of their body was more actively engaged in performing the sorting task (e. g., handling and sorting crabs), reducing the need for postural stabilization from the right erector spinae muscles. In contrast, the non-dominant left side took on a greater role in maintaining postural control and stabilization, as it was less involved in the active movements of sorting.

Supporting this, Łochyński et al. (2024) found that the lumbar multifidus muscles on the contralateral side of a lifted arm show higher muscle activation to help stabilize the trunk during asymmetrical tasks. Additionally, Davey et al. (2002) demonstrated that erector spinae muscles on the contralateral side are activated in a coordinated manner with limb muscles, driven by central neural mechanisms. This coordinated response helps maintain stability and counteract the disturbance caused by limb movement. These findings indicate that hand dominance and task involvement influence muscle activation patterns between the two sides of the body. Such asymmetries should be considered in ergonomic assessments. For instance, in crab sorting tasks, the placement of crabs before sorting and the location where sorted crabs are placed could affect which side of the body is used more heavily. Adjusting the layout to balance task involvement between the dominant and non-dominant sides may help reduce asymmetrical muscle strain.

Upper trapezius muscle activity also significantly increased at the high surface height compared to low on both sides. This increase is likely due to the greater shoulder flexion moments required at higher table heights. As participants raise their arms further to reach the surface, the demand for shoulder elevation and stabilization increases, leading to higher upper trapezius muscle activation to compensate for the greater mechanical load on the shoulder joint. Previous research supports this finding, showing that elevated work surface heights result in increased upper trapezius muscle activity due to the greater shoulder elevation needed (Liu et al., 2022; Seghers et al., 2003). These studies confirm that working with raised arm positions increases the muscular effort required for shoulder stabilization, particularly engaging the upper trapezius.

Furthermore, the results revealed that right-side upper trapezius muscle activity was consistently higher than the left across all height conditions. This asymmetry suggests that the right upper trapezius was more engaged in active movements, likely because participants relied more on their dominant right arm for handling and sorting crabs during the task. The left side, by comparison, may have been less involved in the task, leading to lower muscle activation on that side.

4.4. Perceived exertion and discomfort

Despite some significant differences in biomechanical outcome measures discussed earlier, no significant differences in perceived exertion and discomfort were found among the three table heights. This lack of significant difference in subjective measures could be attributed to the relatively short duration of the tasks. It is important to note that discrepancies between objective measures (e.g., muscle activity, joint moments) and subjective data (e.g., perceived exertion, discomfort) are commonly reported in ergonomics research. Several studies have shown that subjective perceptions often do not align with objective biomechanical outcomes (Parakkat et al., 2007; Wiktorin et al., 1993; Yu et al., 2016). One potential explanation for this is that subjective measures may be influenced by factors such as task familiarity, individual pain tolerance, or perceived task difficulty, which may not directly correlate with immediate physical strain. Therefore, limited differences in perceived exertion and discomfort should not be overlooked, and future studies should evaluate the effects of table heights during prolonged sorting tasks, especially in real vessel settings.

4.5. Strengths and limitations

This study has notable strengths in research design and study setup. Briefly, the experimental setup was designed to reflect the actual setting of crab fishing vessels and real-world tasks involved in crab harvesting. The sorting table used in this study was custom-built by a local fabricator with expertise in constructing crab sorting tables. Additionally, three commercial fishers were consulted to evaluate and confirm the study setup and gears used for the study. To replicate the physical and psychological aspects of crab sorting tasks, we used artificial plastic crab that closely resembled real crab in terms of shape, size, and appearance. Another strength of this study was our relatively large sample size, which allowed for robust statistical analysis and reliability of the results. Moreover, the inclusion of multiple objective biomechanical metrics (muscle activity, joint angle, and moment) combined with subjective measures provided a detailed understanding of how various sorting table heights impact different ergonomics outcomes.

Despite these strengths, several limitations must be acknowledged. First, the study was conducted in a controlled laboratory setting that differs from actual field settings. Environmental conditions present, including vessel motion, slippery surfaces, extreme temperatures, and wet conditions, can potentially affect the physical stress and overall biomechanical load (Park, 2020). Moreover, as the plastic crab used in this study (weighing 150 gr) is lighter than real Dungeness crab (with an average weight of 1 kg), the biomechanical load may have been underestimated. Therefore, future field-based studies may be merited to better represent the crab sorting tasks performed in real-world conditions. Second, the study participants were male volunteers from a university community who

did not have previous experience in crab fishing activities. It is worth noting that having experience and skill in performing a physical task can alter kinematics and muscle recruitment during the task (Bernardi et al., 1996). Therefore, it is possible that the biomechanical load measurements obtained in this study may not fully represent the kinematics and muscle recruitment patterns of experienced crab fishers. To reduce the potential impact of fishing experience on study results, participants were given sufficient time to practice the task prior to the experiment. Nonetheless, future research with actual professional fishers may be merited for a better understanding of the biomechanical load experienced by fishers during crab sorting tasks. Third, the relatively short task duration in this study may only allow for comparisons of instantaneous biomechanical responses by crab sorting table height; therefore, the results do not provide fatigue-related implications but rather serve as baseline estimates of physical demands associated with crab sorting table heights during crab sorting task.

Future research investigating the long-term biomechanical and physiological impacts of repetitive crab sorting may offer valuable insight into its cumulative impact on musculoskeletal health. Lastly, this study only included male participants, potentially restricting our findings to females due to the effect of gender on musculoskeletal biomechanics, including different biological, kinematic, and muscle activation patterns (Martinez et al., 2020). Although commercial fishers are predominantly male, according to previous survey studies (Kincl et al., 2023), future studies should include female participants to enhance the representativeness of the results for both male and female fishers.

5. Conclusion

This study underscores the importance of sorting table heights in reducing biomechanical loads and associated musculoskeletal injury risk among commercial crab fishers. By adjusting table heights, it may be possible to significantly reduce the physical demands on the low back and enhance biomechanical efficiency. Nevertheless, it is essential to consider that while higher table heights can decrease trunk flexion and alleviate lower back strain, they may also increase shoulder flexion moments, potentially contributing to shoulder fatigue over time. As a result, ergonomic interventions should aim to find a balance that minimizes risks to both the lower back and shoulders. Further research is needed to explore the long-term effects of these adjustments, particularly in terms of subjective discomfort, muscle fatigue, and injury rates, to develop comprehensive ergonomic guidelines for the fishing industry. Additionally, future studies should consider the integration of real-world environments and real-time feedback systems to continuously optimize worker postures and reduce injury risks.

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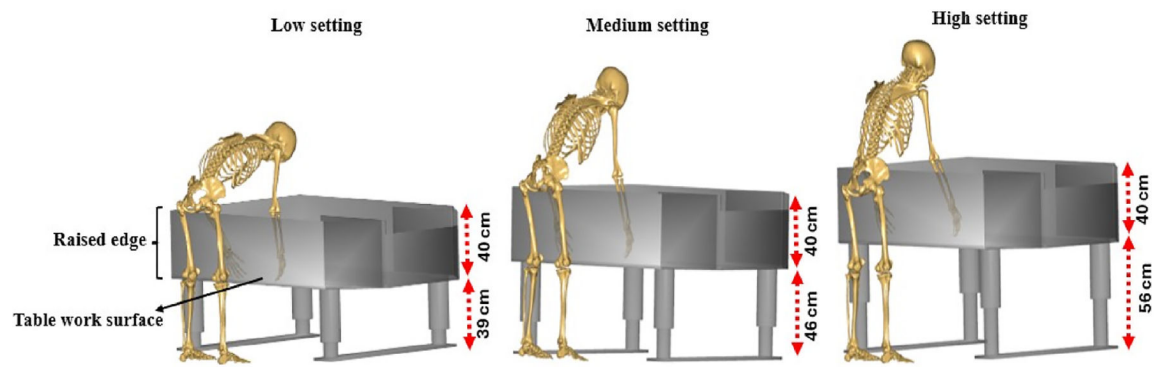


Fig. 1. Table height settings, including low, medium, and high. The work surface height of the sorting table in low, medium, and high settings was 39 cm, 46 cm, and 56 cm, respectively.

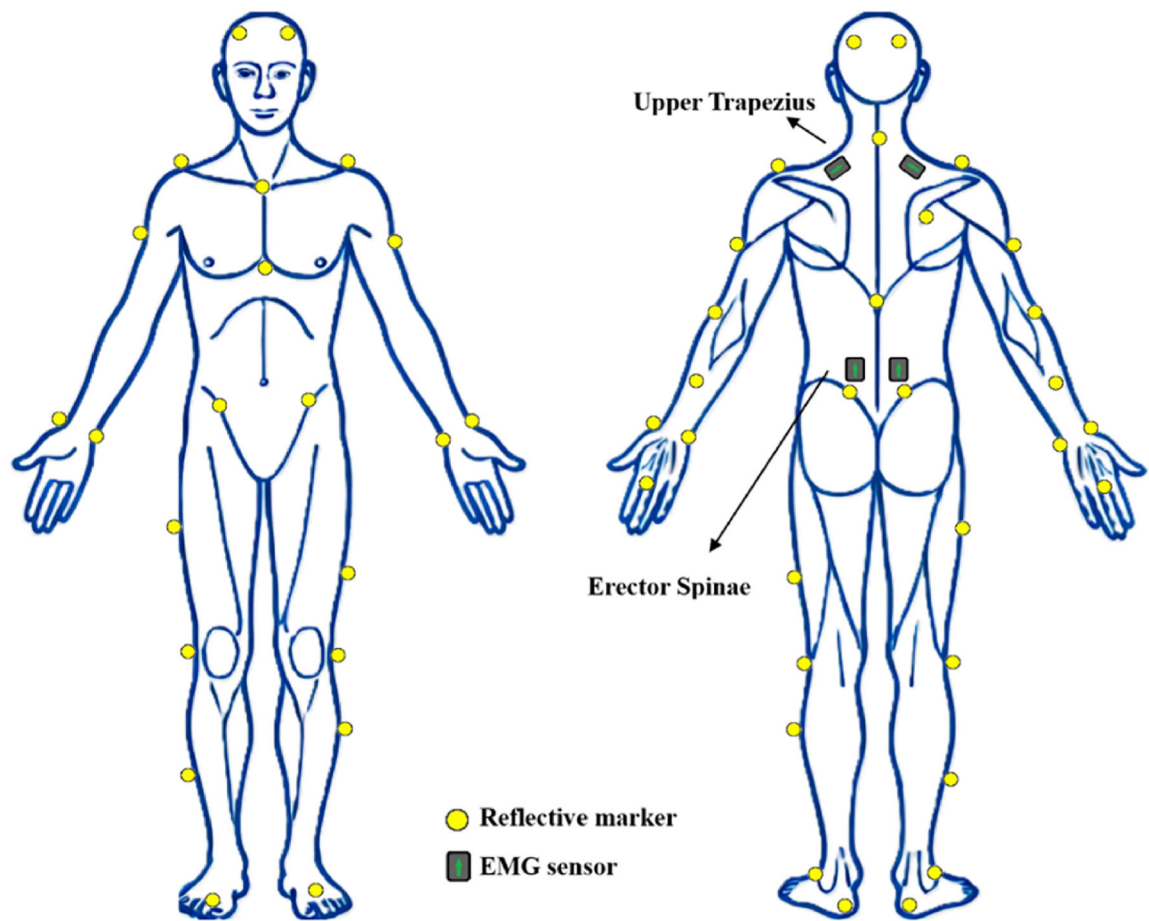


Fig. 2.
Placement of reflective markers and EMG electrodes on participants.

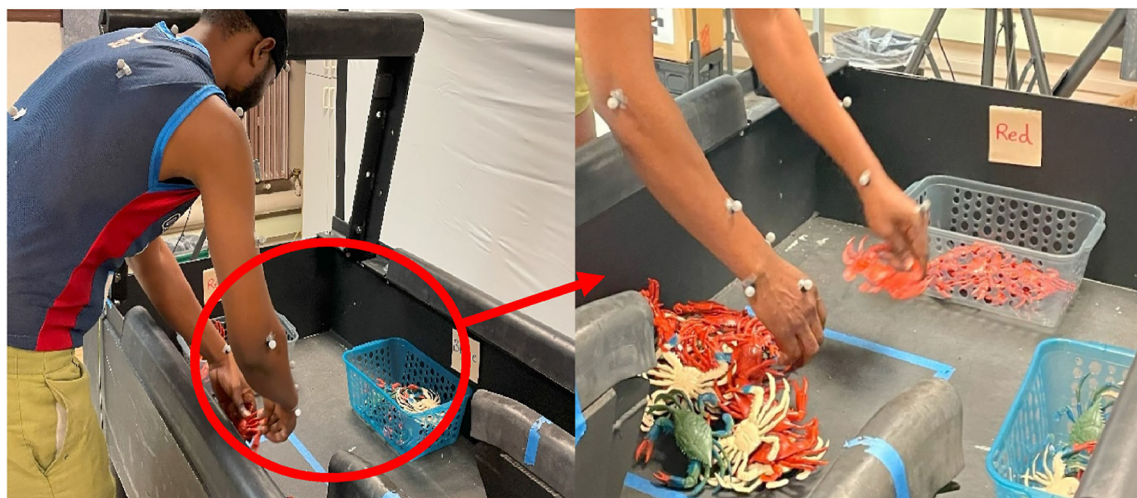


Fig. 3.
The crab sorting task involved sorting 40 plastic crabs based on color on a custom-built sorting table with an adjustable height.

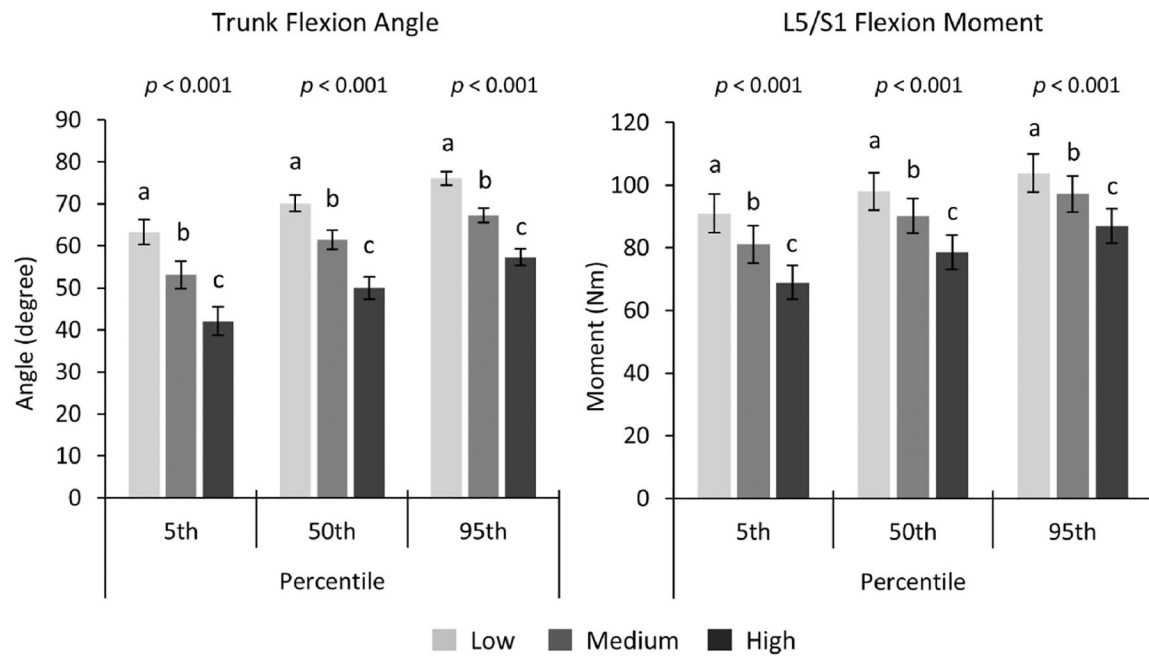


Fig. 4.

Mean and standard error of the 5th, 50th, and 95th percentile trunk flexion angle and L5/S1 flexion moment during crab sorting tasks under the three height conditions [N = 25]. P-values were calculated from mixed models with the sorting table height (fixed effect) and the participant (random effect). Means with no letter in common are significantly different between height conditions in the post-hoc test. For example, means with the letters 'a' and 'ab' are not significantly different.

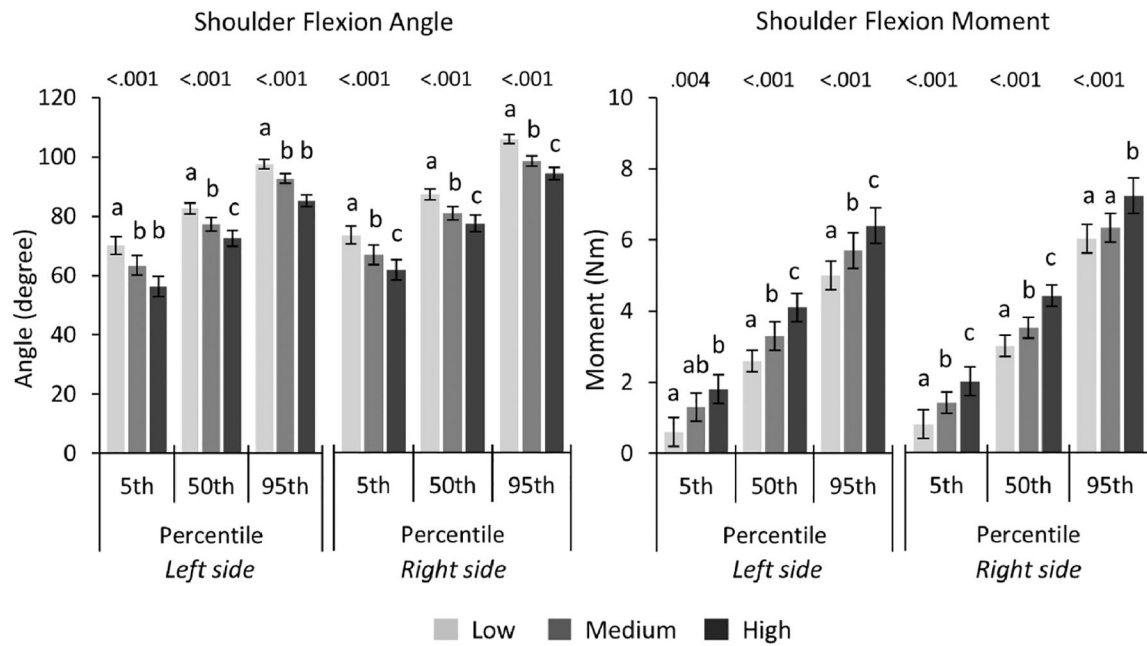
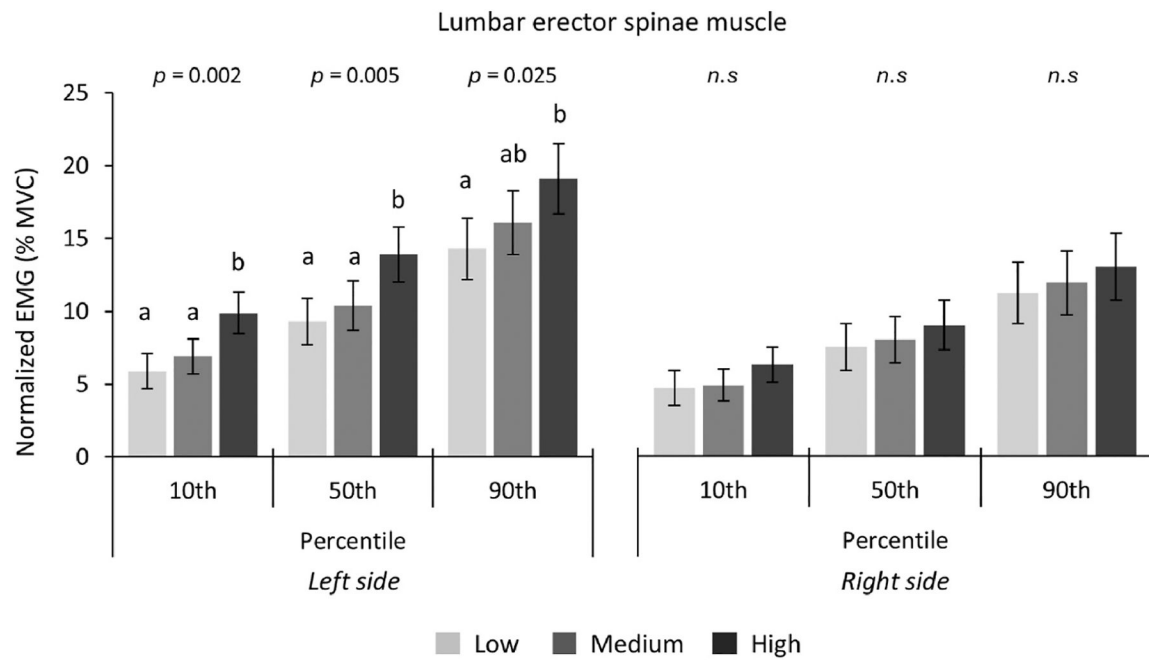


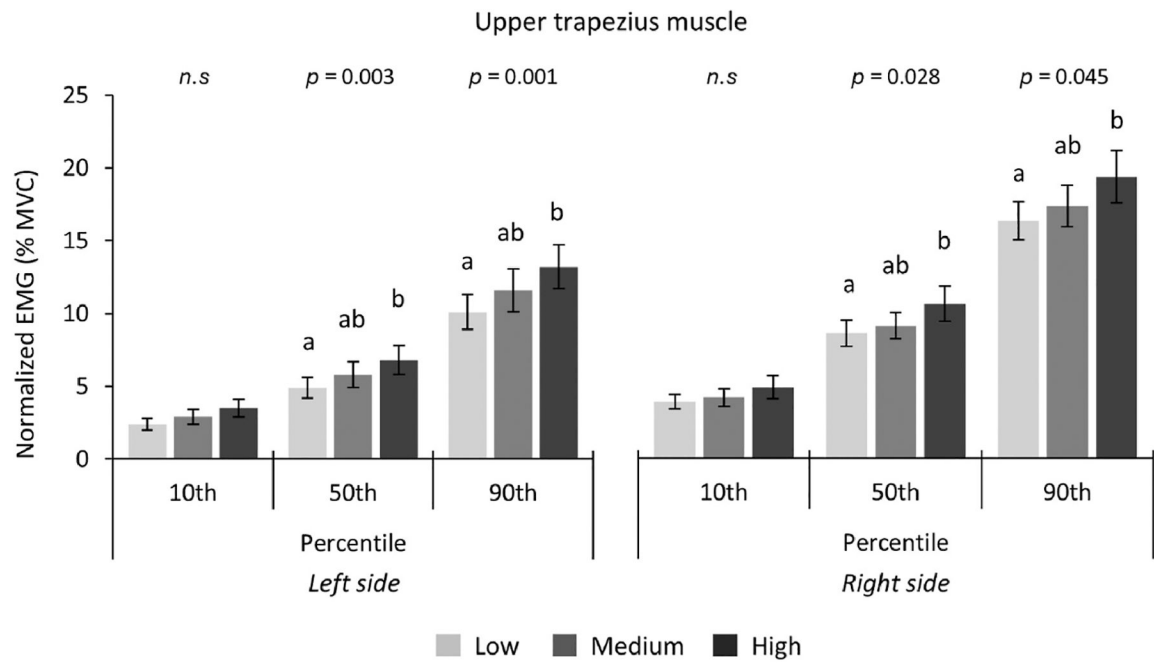
Fig. 5.

Mean and standard error of the 5th, 50th, and 95th percentile left and right shoulder flexion angle and moment during crab sorting tasks under the three height conditions [N = 25].

P-values were calculated from mixed models with the sorting table height (fixed effect) and the participant (random effect). Means with no letter in common are significantly different between height conditions in the post-hoc test.

**Fig. 6.**

Mean and standard error of the 10th, 50th, and 90th percentile muscle activities in the left and right lumbar erector spinae [Maximum voluntary contraction (%MVC)] during crab sorting tasks under the three height conditions [$N = 25$]. P-values were calculated from mixed models with the sorting table height (fixed effect) and the participant (random effect). Means with no letter in common are significantly different between height conditions in the post-hoc test. The abbreviation 'n.s.' indicates non-significance.

**Fig. 7.**

Mean and standard error of the 10th, 50th, and 90th percentile muscle activities in the left and right upper trapezius [Maximum voluntary contraction (% MVC)] during crab sorting tasks under the three height conditions [$N = 25$]. P-values were calculated from mixed models with the sorting table height (fixed effect) and the participant (random effect). Means with no letter in common are significantly different between height conditions in the post-hoc test. The abbreviation 'n.s.' indicates non-significance.

Table 1

Demographic and anthropometric characteristics of study participants.

Variable	N = 25	
	Mean	Standard Deviation (SD)
Age (year)	34.2	13.3
Height (cm)	181.6	3.0
Weight (kg)	88.6	10.1
Body Mass Index (BMI)	25.67	5.41
Shoulder height (cm)	149.44	5.7
Elbow height (cm)	110.05	4.01
Knuckle height (cm)	78.59	4.33
Waist height (cm)	107.51	6.78

Table 2
Mean and standard deviation of perceived exertion and discomfort during crab sorting with three heights [N = 25].

Variables	Height Condition			Height	Time				
	Low	Medium	High	p-value	p-value				
Perceived exertion	Whole-body (RPE)			10 (±0.5)	9.4 (±0.4)	9.0 (±0.5)	0.087	–	
	Shoulder (CR-10)			1.4 (±0.2)	1.6 (±0.3)	1.8 (±0.4)	0.603	–	
	Low back (CR-10)			3.8 (±0.4)	3.7 (±0.4)	3.0 (±0.4)	0.083	–	
Discomfort (CR-10)	Shoulder			Pre	0.9 (±0.3)	0.6 (±0.2)	0.6 (±0.2)	0.538	0.034
				Post	1.2 (±0.3)	1.0 (±0.3)	1.1 (±0.4)		
	Low back			Pre	2.1 (±0.4)	1.4 (±0.3)	2.2 (±0.4)	0.145	<0.001
				Post	3.4 (±0.4)	2.9 (±0.4)	2.3 (±0.4)		