International Journal of Industrial Engineering, 30(3), 763-780, 2023

OPERATIONAL AND INTELLIGENT ANALYSIS UNDER THE ERGONOMICS APPROACH OF THE PREVALENCE OF MUSCULOSKELETAL DISORDERS IN CONTAINER OPERATORS

Ricardo Luís Alves da Silva[1, 2], Kleber Gonçalves Bezerra Alves[1], Alvaro Antonio Ochoa Villa[1, 2, *], José Ângelo Peixoto da Costa[1, 2], Frederico de Menezes Duarte[1, 2], Ana Karina Pessoa da Silva Cabral[3], and Paula Suely Arruda Michima[1]

[1]Department of Mechanical Engineering
Federal University of Pernambuco
Recife, Brazil

[2]Academic Department of Undergraduate Course, Mechanical Engineering
Federal Institute of Pernambuco
Recife, Brazil
[*]Corresponding author's e-mail: ochoaalvaro@recife.ifpe.edu.br

[3]Department of Occupational Therapy
Federal University of Pernambuco
Recife, Brazil

This study aims to evaluate the prevalence of musculoskeletal disorders and possibly associated working conditions among dockworkers operating quay cranes. The data on working posture were collected through direct observations, photographs, and videos used in the Rapid Entire Body Assessment. The data on discomfort were collected using the Nordic Musculoskeletal Symptom Questionnaire. First, the questionnaire results showed that musculoskeletal symptoms are highly prevalent, particularly in the lumbar spine, cervical spine, shoulder, and neck. These data were ratified by machine learning analyses that, using logistic regression, achieved a big root mean square error, showing a correlation in the neck, wrists and hands, hip and thigh, and cervical region. Secondly, the final Rapid Entire Body Assessment score was 6, which reveals the median to the high-risk level of worker posture while performing the task.

Keywords: Musculoskeletal Disorders, Ergonomics, Rapid Entire Body Assessment, Inadequate Postures, Machine Learning, Quay Crane.

(Received on November 7, 2022; Accepted on May 20, 2023)

1. INTRODUCTION

Technological advances in the industrial area result in increased production, with machinery increasingly capable of adding quality and speed to a process. Due to the increasing use of microelectronics and software engineering, these factors, among others, have contributed to an increase in the demand for operators of these machines who, in turn, are submitted to jobs that require an increasing physical and cognitive effort (Oestergaard *et al.*, 2022).

With the advent of Industry 4.0, or the fourth industrial revolution, the integration between machines and software is progressively more latent, using technologies for automation and data exchange, concepts of cyber-physical systems, the Internet of Things, and cloud computing (Fraske, 2022; Javaid *et al.*, 2021). These technologies will soon make it possible to monitor production activities in real-time and establish intervention strategies for human procedures, aiming to mitigate deviations that may affect their physical and cognitive health (Baum-Talmor and Kitada, 2022; Beier *et al*., 2022).

Following this growth, while facing a demand for high production, the transportation and logistics systems were forced to respond with the creation of plans for the control, storage, and transportation of raw materials and manufactured goods. The capacities of land, sea, and air transportation had their volumes grow geometrically. According to IMO (2022) data, about 80 percent of global trade is transported by sea. Moreover, shipping constantly evolves and plays an increasingly important role in trade and the world economy. According to the UNCTAD Handbook (2020), the world's ocean freight transport grew in 1970 from 2566 million tons to 11 billion tons in 2019. Seaports are facilities important to a country's

DOI: 10.23055/ijietap.2023.30.3.8709 ISSN 1943-670X

economy since the cargo handled each year increases significantly. Port activities are usually associated with problems related to dust and noise, back injuries, falls, crane accidents, waste generation, dredging operations, water pollution, air pollution, soil contamination, and handling of hazardous substances. As contributory factors to this reputation are the lack of an efficient safety culture, inadequate risk assessment and operations management, inadequate operating procedures, lack of training and consciousness, larger and faster port equipment, and ships of greater capacity (Corrigan *et al.*, 2019)

Currently, the use of containers for cargo handling in ports is growing due to the convenience of placing them on ships and transporting them on trucks and train wagons. According to data presented by the World Shipping Council, in 2021, from the ranking of container handling ports, the largest ones in the world are in the Asian region, mainly in China. The port of Shanghai, China, in 2020, handled 47.5 million TEU (Twenty Feet Equivalent Unit - container unit of measure) (WORLDSHIPPING, 2022). There is a worldwide standardization of their dimensions, and the ports are equipped with specially developed container handlers (Luo and Wu, 2020). These machines handle the containers in the storage yard of the port, as well as loading and unloading ships. The handling volumes impose an accelerated and intense pace of work on the operators, progressively exposing them to exhausting workdays with limited breaks (Wongwien, 2017). Posture is "the maintenance of body segments in space" (Moraes and Mont'alvão, 2003). According to Iida (2016), for ergonomics, posture is the study of body positioning in the work environment, such as the head, trunk, and limbs. The redesign of workstations and the use of tools to improve posture promotes the reduction of fatigue, body pain, time off work, and occupational diseases (Antwi-Afari *et al*., 2021).

Repetitive work and the postures exerted can affect various regions of the body of these operators, bringing musculoskeletal symptoms that can lead to diseases (Constantinos *et al*., 2016; Jafari *et al*., 2016; Pallis, 2017). In this sense, several studies have been conducted to find better-operating techniques and more appropriate criteria to maintain this activity that is vital to the economy and the safety of operators (Oakman *et al*., 2022)**.**

In the United States of America (USA), more than 600,000 musculoskeletal disorders (MSDs) accounted for $54 billion in costs on one-third of all lost workdays and led to 2014 (Kang *et al*., 2014). Affected workers are subject to loss of quality of life and adverse performance because MSDs damage body structures such as muscles, tendons, ligaments, cartilage, bones, joints, and nerves (Goes *et al*., 2020; Smith *et al*., 2020). In Brazil, a study by the Ministry of Health called "Saúde Brasil," published in 2018, pointed out that Repetitive Strain Injuries (RSI) and Work-Related Musculoskeletal Disorders (WMSD) are the diseases that most affect Brazilian workers. The Ministry of Health survey showed that in 10 years, the two diseases account for 67,599 cases among workers in the country, representing a 184% increase in the index over the same period (Ministry of Health, 2019). The statistical data drives numerous studies in preventing musculoskeletal disorders and seeking solutions to mitigate their consequences.

A Rapid Entire Body Assessment – REBA was developed to evaluate unpredictable whole-body work postures to identify postures sensitive to musculoskeletal risk factors. This method uses records based on movement plans in the investigation process, discriminates muscular activities caused by unstable postures, then categorizes the actions and generates urgent recommendations. MSDs not only develop disabilities and suffering for the worker but also result in high costs to society. They are defined as injuries or dysfunctions that affect muscles, tendons, ligaments, joints, peripheral nerves, and nerve roots in different body segments such as the neck, shoulder, elbows, forearms, wrists, hands, lower back, and lower limb segments. The risks for the development of these disorders are multifactorial and include individual factors (obesity, age), work-related physical factors (repetitive movements, heavy work, frequent bending, whole-body vibration, inadequate postures), and psychosocial factors (Costa and Vieira 2010).

In a comparative study searching for the best mopping technique, Yang *et al*. (2022) evaluated musculoskeletal risk factors (repetitions, posture, forces) of the upper limb during floor cleaning tasks. The analysis sample was 200 women interviewed to determine the most common cleaning system, cleaning patterns, and type of flooring used in their homes and consider the REBA method. All participants felt the cotton fiber mop cleaned best, and all three mops had medium postural risk. As a significant result, the highest repetition count and effort rates were observed on the flat mop during cleaning and mopping tasks.

Using the same method, Joshi and Deshpande (2020) presented a sensitivity study on the Rapid Entire Body Assessment (REBA) and the identification of insensitive and sensitive posture zones, aiming to identify posture scores that do not change with changing input parameters. The study indicated that many insensitive posture zones do not modify the postural dependent scores when the independent body member scores are changed. In the search for a risk assessment tool, Yazdanirad *et al*. (2022) proposed an instrument (PRAMUD) to assess the risk of musculoskeletal disorders among workers. A total of 300 male employees in a steel mill were considered. Personal data were collected through interviews. In addition, they were asked to complete the Persian version of the Cornell musculoskeletal discomfort questionnaires (CMDQ). It was found that personal parameters and physical items play a significant role in predicting disorders. Thus, the PRAMUD tool can be used to assess the risk of musculoskeletal disorders in people with varied personal and occupational characteristics. The method adequately estimated the risk levels of musculoskeletal injuries by solving the overestimation problem. Thus, using this tool can timely warn of the danger and prevent the occurrence of musculoskeletal disorders.

Rodrigues *et al*. (2019) performed a cross-cultural adaptation of the ROSA (Rapid Office Strain Assessment) into Brazilian Portuguese. They evaluated the psychometric measures of reliability (internal consistency, intra- and inter-observer reliability, and measurement error), construct validity (cross-cultural validity and hypothesis testing), and accuracy in a sample of occupational health professionals and computer office workers. Forty-three occupational health professionals (observers) and 90 workers were engaged in this study to perform the cross-cultural adaptation of the ROSA into Brazilian Portuguese (ROSA-Br) and assess its psychometric properties. A moderate accuracy was verified in the final ROSA-Br score of 6, which confirmed the suitability of ROSA-Br for assessments and ergonomic field research. Luzio *et al.* (2020) introduced a visual and vibrotactile feedback technique in an upper limb rehabilitation robot platform. The approach was proposed to ensure ergonomic posture during rehabilitation. Ten healthy subjects were involved in this study. Two feedback modalities were used to provide information about incorrect neck and trunk posture. The results revealed that both feedback modalities are reasonable solutions for providing posture information. However, looking at the average reaction time, visual feedback was more intuitive than vibrotactile feedback.

Lowe *et al*. (2019) presented a contemporary perspective on assessment tools and methods and information on using computer programs or mobile applications to aid workplace analysis by ergonomics professionals. The objective was to reduce manual identification and thus improve and decrease the work time of ergonomic assessment. Therefore, using mobile device applications for such methods seems to be in an early implementation phase. In surgical procedures, Sancibrian *et al.* (2020) aimed to provide information on better ergonomic and usability characteristics required for these interventions and presented a prototype of a handle used in laparoscopic surgery instruments. Among the most impactful results, they found lower pain levels and reduced wrist hyperflexion. In the same context, but directed towards prevention and occupational safety, Garosi *et al*. (2022) proposed and analyzed a passive head/neck support exoskeleton as a possible ergonomic intervention for work applications with hands above shoulder height. The need for extra support in the regions of the upper limbs to reduce tension in the shoulder region was verified. Enez and Nalbantoglu (2019) conducted a comparative analysis of the effects of musculoskeletal disorders (MSDs) associated with different work postures during harvesting under varying outdoor conditions. They compared the work stages using the Ovako Work Posture Assessment System (OWAS) (REBA). The intention was to assess mechanisms and techniques to help monitor ergonomic problems in harvesting operations. A difference was found between the OWAS and REBA results, establishing that the two methods were developed considering different types of work and that neither method was designed for forestry. In addition, OWAS was found that the most suitable MSDs risk assessment method in the forestry industry.

A similar study was proposed by Kee *et al*. (2020), where the comparative analysis was directed to the maximum retention times (MHTs) for body postures. The observational methods studied were: (OWAS), Rapid Upper Limb Assessment (RULA), and (REBA), based on MHTs. The analysis sample consisted of 17 healthy male graduate students with no history of musculoskeletal disorders. The RULA rated the postures tested in the experiment as more stressful than the OWAS and REBA, and the final RULA score was more sensitive to MHTs. Finally, and based on the results, it is concluded that the RULA method is better at evaluating postural loads under these conditions.

In the construction industry, specifically in bricklaying activities, an evaluation alternative was introduced by Pan *et al.* (2021), where the impact of a mast climbing platform (MCWP) designed on the trunk motion and postural stability of workers while performing bricklaying tasks was evaluated. The results indicated that using the L-shaped production bench reduced the lowest trunk range of motion and trunk angles in all three planes compared to the straight-shaped production bench and the conventional approach of not using a production bench. In addition, both body sway velocity and area were significantly reduced. Seidel *et al*. (2021) proposed developing a method based on the Limit Value for Hand Activity Level (TLV for HAL). Kinematic data (average power frequencies, angular velocities, and micro-pauses) were used to measure HAL. In the case of TLV, it was generated from the combination of electromyographic data (mean square values). Overall, the measurement proved suitable for use in the field with many workers.

Lantonie *et al.* (2022) conducted a comparative study to evaluate the levels of hardness of car seats, considering two levels exclusively (S1 - soft and S2 - firm) and different types of roads (city, highway, mountain, country) on the distribution of the pressure profile and perceived discomfort during prolonged driving. The analysis sample was twenty participants who drove two 3-hour sessions (one per seat) in a static simulator car. According to the results, the softer seat, S1, induced a larger contact surface on the cushion and backrest, reflecting a better pressure distribution. The pressure distribution was less homogeneous on mountain and city roads than on monotonous roads (road and countryside). Despite the differences in pressure between the seats, both led to similar increases in perceived whole-body discomfort throughout the driving session. In addition, the highest discomfort scores were in the neck and lower back, whichever seat.

Machine learning (ML) can be briefly defined as computational methods capable of learning about the behavior of a given set of data based on the construction of deterministic or non-deterministic relationships between the input and output data of "intelligent" models built in a supervised, unsupervised, or reinforcement way (Russell and Norvig, 2021), (Helm *et al.*, 2020). ML methods are used to solve different issues based on their ability to process databases of different sizes and fast responses from trained models. Among the many applications of ML methods are the resolution of classification, regression, data mining, and computer vision problems (Shinde and Shah, 2018).

In the treatment and analysis of research results in accident and occupational disease prevention, ML has presented great results in predicting the behavior of these phenomena. ML refers to using algorithms to optimize a performance criterion using training data and or previous experience (Alpaydin, 2020). Es (2022) report that it is a growing trend in many industries due to technological advances that increase the volume of data collection and have better processing capabilities.

Villalobos and Cawley (2022) used artificial intelligence (AI) and machine learning techniques to perform task classification and ergonomic evaluations in work environments. They proposed using simple sensors based on inertial measurement units (IMU) attached to workers' wrists in a slaughterhouse to measure human activity, capture movement-related information, and determine their risk of experiencing MSDs. The results indicated that it could accurately classify knife sharpening and predict the worker's RULA score. The algorithm achieved 98% accuracy in predicting the RULA score on the test dataset, which suggests a solid ability to assess the ergonomic risk the workers suffered adequately. In the same research area, Chan *et al.* (2022) applied ML techniques to analyze and prevent WMSD. A scoping review was conducted using seven literature databases. It was observed that ML techniques contributed significantly to developing interventions, identifying risk factors, and the incidence of MSDs, among others. Almost a quarter (23.8%) of all included studies were published in 2020. These findings provide information on the comprehensiveness of ML techniques used for the primary prevention of MSDs and may help identify areas for further research and development.

Rawson *et al.* (2021) presented an ML approach to monitor ship safety under extreme weather conditions. The potential of such algorithms to quantify the relative probability of an incident during the United States Atlantic hurricane season was investigated by training an algorithm on vessel traffic, weather, and historical accident data to identify accident candidates from recorded vessel tracks. Among the various methods tested, Support Vector Machines performed well. The model results show modest success in predicting accidents. In general, the techniques can distinguish accidents from non-accidents. However, there are a significant number of false positives that reduce accuracy.

In the context of this research work, it is essential to note that the QC operator is a highly specialized labor force in handling containers in loading and unloading vessels. They perform their activities in a sitting posture for extended periods (4 to 7 consecutive hours) in an organizational climate that subjects the operator to a high burden of responsibility and pressure for productivity since equipment and vessel time costs are high. High levels of performance and pressure to maximize productivity are constant elements of their daily activity. Vibration can also contribute to the onset or worsening of musculoskeletal symptoms, being one of many contributing pathogens. It is recommended that crucial ergonomic factors be considered in any vibration assessment. According to Mansfield (2005), other risk factors besides poor postures, such as sitting for too long periods, weightlifting, and working in the cold, are often associated with environments where whole-body vibration is also present. Fatigue and musculoskeletal pain can influence postural control, which can increase the risk of errors and can result in reduced quality of work or production and dangerous situations. Good ergonomic design is a basic necessity to avoid these adverse effects. In practice, the ergonomic evaluation of work is performed through methods/tools and standards, which consider a group of working conditions and a specific focus, best defined by Másculo and Vidal (2011). Among the most diverse tools, the most used are NIOSH, OWAS, RULA, and REBA, the latter being the most suitable for the evaluation of postures of upper and lower limbs.

The need to optimize port operations for loading, unloading, and storing containers has become imperative since the current large volumes of movement are increasingly making manual control unfeasible from an economic and operational point of view. The completely manual operation is time-consuming and brings several health problems to the operator. It is noteworthy that several technologies have been developed to optimize safety and reliability in the operation of cranes. Crane monitoring is the subject of numerous research focusing mainly on visualization, communication, and systems integration. Lee *et al*. (2020) combined radio frequency identification and machine vision technology to provide crane operators with more detailed information about the work environment and objects to be transported during the operation. Price *et al.* (2021) presented a multi-sensor real-time crane monitoring system consisting of load tracking, obstacle detection, worker detection modules, collision warning, and 3D visualization. A combination of encoders, displays, and laser scanning systems are used to reconstruct a 3D workspace model crane environment and provide real-time spatial feedback to the operator. Zhou *et al.* (2022) created a system based on digital twins for harbor cranes to solve the problems of the lack of an online data simulation test environment, little openness of data collection, and the low degree of data visualization in the online control process of harbor cranes.

The present research aimed to conduct a pioneering study on the prevalence of musculoskeletal symptoms in QC operators at a port in northeastern Brazil. Employing the REBA tool, we evaluated the complaints of symptoms and the postures exercised during the workday, establishing the current context of ergonomic risks with the application of machine learning and, finally, suggesting mechanisms of evaluation and control for disease prevention.

2. MATERIALS AND METHODS

The equipment that handles containers in ports is the quay cranes (QC), which load and offload the containers onto the ship, as shown in Figure 1. The transtainer performs the transportation of the containers in the storage yard together with the reach stacker (RS). The transport of the containers from the storage yard to the quay, and vice versa, is done by the internal movement vehicle (IMV), also known as the tractor. In this work, we delimited the object of study to the workstation of the QC operator.

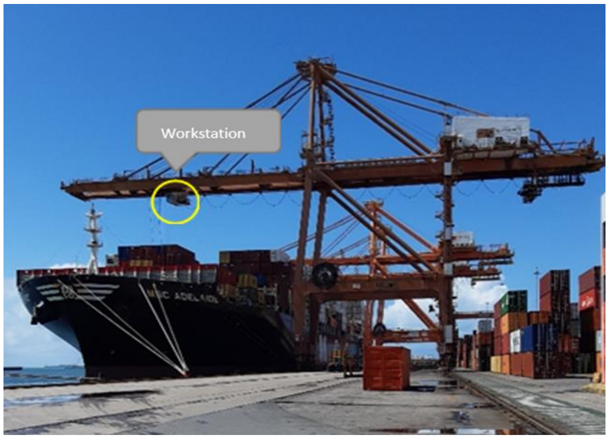


Figure 1. Quay crane: the workstation of the operators under analysis

The working positions adopted by the operators of such machines were studied since it is suspected that they can cause musculoskeletal disorders. The operator's cognitive load is constantly demanded since he controls the crane using a joystick and needs to observe the motion of the container on the ground, being assisted by an auxiliary on the quay. The view of the handling is via transparent walls and floors that force the operator to look down constantly, making them adopt static and unusual postures for long periods, demanding mainly the trunk and neck, as shown in Figure 2.

Figure 2. The posture of the QC operator

The pressures on the seats of the container operators were studied. It was found that the operators change their position in time to reduce the pressure in the buttock region and take these pressures to the thigh region. The change in position consists of a forward movement of the hip joint, probably to reduce the concentrations of pressures due to the greater presence of ischial tuberosities. However, the contact between the back and rear seatback was minimal (PAU *et al*., 2016).

This research is characterized as descriptive, conducted through a field study, with a quantitative approach (GIL, 2022). Data collection was conducted from November 2021 to February 2022. It took place at the facilities of a port terminal in northeastern Brazil, where the operations at workstations with container handling machines were studied with an ergonomic focus on the analysis of work posture and its consequences for the health of operators. We delimited the analysis to the QC responsible for loading and unloading ships, according to Figure 01. The visits to the production areas took place weekly, and the sample was characterized according to Kirkwood & Sterne (2006). We sampled a total of 12. For the case of small samples of a finite and known population, being the case under study, which totals a population of 23 container operators, a minimum of 5 operators could be sampled.

2.1. Data Collection Tools

The tool adopted to investigate musculoskeletal symptoms was the application of a form to survey the profile and health complaints of the operators. An adaptation of the Nordic Musculoskeletal Questionnaire (NMQ) (KUORINKA *et al*., 1987) was used, which is an epidemiological data collection tool widely used in primary studies in the occupational area. The original tool proposed by Kuorinka *et al*. (1987) consists of a standardized questionnaire for analyzing musculoskeletal symptoms in an ergonomic or occupational health context. The questions force a choice of variants and can be self-administered or used in interviews, focusing on symptoms most frequently found in the occupational environment (BISPO *et al*., 2022).

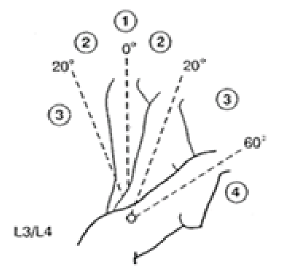
Regarding the operators' posture analysis, an ergonomic evaluation of the work was applied using postural analysis techniques to investigate whether the typical work posture contributes to the onset or worsening of musculoskeletal symptoms in operators. Among the known ergonomic assessment tools, the Rapid Entire Body Assessment - REBA (HIGNETT and MCATMNEY, 2000) was identified as one of the most appropriate for the context since it performs a complete body analysis. The REBA analysis has proven to be an excellent tool for this kind of postural assessment. It is being used frequently by Ergonomics researchers, as in the works carried out by Enez and Nalbantoglu (2019), Kee *et al*. (2020), and Yang *et al*. (2022), which in most cases have revealed alarming risk factors in several areas of manufacturing and services. We used filming and photographs of the operator performing his activities to apply the REBA method. When possible, we applied the method on-site using the goniometer, shown in Figure 3a. In most cases, we used the angle measurement tool of the KINOVEA software (Charmant, J., & contributors., 2021), as shown in Figure 3b. The ergonomic analysis by the REBA method was applied to the longest posture in the operator's work interval, and the collected data were fed into the REBA postural load application of the Instituto Nacional de Seguridad y Salud en el Trabajo – INSST (INSST, 2022)

(a) (b)

Figure 3. a) Goniometry; b) Software KINOVEA

The REBA method allows the evaluation of static and dynamic postures and sudden or unexpected changes in posture. According to Hignett and McAtmney (2000), the method allows the analysis of the postures adopted at work, the forces applied, the types of movements or actions performed, muscular activity, repetitive work, and the type of grip adopted by the operator when performing the work. It divides the body into segments, each one to be coded individually, as illustrated in Table 1, and evaluates the risk levels in the upper limbs, trunk, neck, and lower limbs. The trunk, neck, and legs are assigned an A score, and the arms, forearms, and wrists are assigned a B score. With the results of A and B, a score of C is defined, which, added to extra scores, culminates in the total points that define the level of intervention action needed in the analyzed posture. It is worth mentioning that each step of the method corresponds to a single posture, and extra scores are attributed during the analysis and calculation. This increment is done according to situations argued by the method that can increase or decrease the risk perception, such as handgrip strength, weight supported, rotation, flexion, or elevation of some members. The method should be applied to the most representative postures to analyze them. Assessing the set of results allows the evaluator to determine whether the posture presents a high risk of injury. The REBA method guides the evaluator on whether to plan corrective actions on specific postures. On the other hand, the individual scores obtained for body segments, load, grip, and activity can guide the evaluator on the aspects with more significant ergonomic problems to implement preventive measures.

Table 1. Score A for the trunk. Adapted from Hignett and McAtmney (2000)

Position	Score	Change in score
Straight trunk	1	+1 score if there is twisting or sideways bending of the trunk.
The trunk is between 0 and 20 degrees of flexion or 0 and 20 degrees of extension.	2	
The trunk is between 20 and 60 degrees of flexion or more than 20 degrees of extension.	3	
The trunk is bent more than 60 degrees.	4	

Another positive aspect of this tool is that, by dividing and coding the body segments individually, it allows evaluation of the segment (risks of muscle injuries, dynamic and static muscle activity, abrupt changes, and unstable postures) with an indication of more urgent ergonomic intervention. Table 2 of the method illustrates the actions to be taken with the final score of the analysis.

Table 2. REBA action levels. Adapted from Hignett and McAtmney (2000)

Final Score	Action Level	Risk Level	Action
1	0	Negligible	No action is required
2 – 3	1	Low	Action may be required.
4 – 7	2	Medium	It is necessary to take action.
8 -10	3	High	Short-term action is needed.
11 – 15	4	Very high	Immediate Action.

2.2. Implementing accident prediction via intelligent regression models

The collected data resulting from the application of the questionnaire were treated using regression models, with input values of the results obtained from the questionnaire of skeletal muscle symptoms, using the following parameters: age, gender, height, weight, laterality, physical activity, and consumption of alcoholic beverages. The regression models were implemented in Python, using the sci-kit-learn library to build different ML models (Pedregosa *et al*., 2011). The values previously obtained were normalized in the interval [0, 1] for numerical variables, such as age, weight, and height. The results obtained transformed the other categorical variables into numeric values 0 or 1, where the answer YES was converted to 0, and NO was converted to 1. Next, the regression models were trained, with univariable output, considering as response variables for each training session one of the types of discomfort or pain previously obtained, namely: neck (TG1), shoulders (TG2), wrists and hands (TG3), knees (TG4), lower back (TG5), back (TG6), neck (TG7), and hip/thighs (TG8).

The regression models used were logistic regressor, decision trees, and linear regressor. Each regression experiment was performed with a random data set, where 75% was a training set, and 25% was a test set. The experiments for each regressor model were performed in replicates of n=5, obtaining for each experiment the values of the following evaluation metrics: mean square error (mean value and standard deviation) and R2 (mean and standard deviation). All data collection tools were only effectively applied after the participants' consent and signature of the informed consent form - ICF, as determined and guided by the ethics committee of the Federal University of Pernambuco.

3. ANALYSIS AND DISCUSSION OF THE RESULTS

This section presents and discusses the results of the questionnaire surveys and REBA analysis. Initially, the questionnaire results were organized, and the data were tabulated and compiled in bar charts. The REBA analysis had its scores calculated and presented in percentage terms in tabular form. Finally, a machine learning analysis was applied to the questionnaire results analyzing the correlations to predict the symptoms.

3.1. Musculoskeletal Symptoms Reports

The preliminary results of the application of the NMQ are summarized in Table 03. The port terminal, the object of this research, at the time of data collection had 23 QC operators, and the universe analyzed was 12 workers (52.17%). The workers were between 30 and 59 years old, with a mean value of 40 years. All of them said they were not smokers, and of the total number of participants, 83.33% did not consume alcoholic beverages. The average weight was 80.41 kg, and the average height was 174.27 cm. Most interviewees were male and right-handed, and only 50% practiced physical activity. The results of complaints of discomfort or pain in the last twelve months of the NMQ are shown in Figure 4, and it was found that in all investigated body regions, more than 50% of the answers were positive. The highest rates of complaints were in the region of the lower back and wrists/hands, which accumulated 83.33% of positive responses, respectively.

Table 3. NMQ Preliminary Results

Variables in study		
Age	Average	40
	Range	30 a 54
Gender	Male	91.67%
	Female	8.33%
Height	Average	174,27
	Range	168-183
Weight	Average	80.41
	Range	65-90
Laterality	Right-handed	91.67%
	Left-handed	8.33%
Physical activity	Yes	50%
	No	50%
Smoker	Yes	0
	No	100%
Consume alcoholic beverages	Yes	16.67%
	No	83.33%

The results showed a prevalence of musculoskeletal symptoms in the region of the lumbar spine, wrists, and hands. The cervical spine, neck, and shoulder regions were tied in second place, with 75% of positive responses regarding discomfort or pain. The hips and thighs were in third place with 66.67%, and the knees and thoracic finished with 58.33% of complaints of discomfort or pain.

Table 4 details the results of musculoskeletal symptoms by body region in the last twelve months, also indicating, when applicable, whether the affected limb was the left or the right. Another essential piece of information was the need for the operator to undergo any treatment for pain or discomfort relief, which in most reports had the highest incidence in the left wrist and hand region with 41.67%, followed by the right shoulder with 33.33%. The need for treatment for the spine region accounted for 25% of the total. The NMQ also indicated that in the last twelve months of the universe surveyed, two workers had to entirely suspend work because of discomfort or pain in one or more body regions considered.

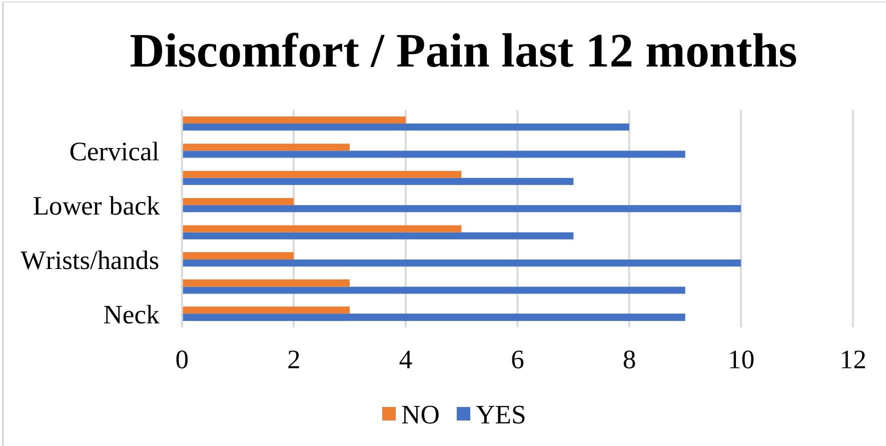


Figure 4. Prevalence of symptoms by body region

Table 4. Detailed results of prevalence of musculoskeletal symptoms

Body region		Discomfort/Pain		Had treatment	
		Yes	No	Yes	No
Low back		10	2	3	9
Thoracic		7	5	3	9
Cervical		9	3	3	9
Neck		9	3	1	11
Hip/thighs		2	10	2	10
Shoulders	Left	5	7	1	11
	Right	9	3	4	8
Wrists/hands	Left	7	5	5	7
	Right	8	4	4	8
Knees	Left	3	9	2	10
	Right	7	5	3	9

Studies conducted in many countries, such as the USA, India, and Brazil, showed a significant public health problem prevalent in industrialized and developing countries. They are serious health problems (Jadhav *et al*., 2019; Rathore *et al*., 2020) and significantly impact workers and the world economy (Woolf *et al*., 2012;). Recently published works ratify the information and reveal that the low back, shoulders, and cervical spine are the areas most affected by these disorders (Okuyucu *et al*., 2021; Schwartz *et al*., 2019; Rathore *et al*., 2020).

3.2. Postural Analysis Results

With the results of the A score and B score, as described in section 2.2, we identified the final REBA method score used to indicate the risk level of the posture and suggested level of action for improvement. Table 5 presents the frequency and percentage of participants with the REBA scores (A score, B score, and final REBA score) for each body region predefined by the method. Of the participants, 91.6% scored 2 (low-risk level) for the neck, indicating they were leaning their necks forward at 20° or more while performing their task. The trunk score for all participants was 3 (also low-risk level), indicating that participants frequently undergo forward leaning between 20º and 60º during the crane operation. The leg score for 83.3% of the participants was 1 (no risk), reflecting that the operator works seated and distributes weight bilaterally. The combined results were compared to the "A" score table, indicating that 75% of the respondents scored 4 (medium risk level, it is necessary to take action), followed by 2 (16.7%) and 1 (8.4%).

Table 5. REBA scores with frequency and percentage of participants

REBA score	Neck	Trunk	Legs	A Score	Arms	Forearms	Wrists	B Score	C Score	Final Score
1			10(83.3%)							
2	11(91.6%)		2(16.7%)		12(100%)	12(100%)	12(100%)			
3	1(8.4%)	12(100%)						12(100%)		
4				9(75%)					11(91.6%)	
5				2(16.7%)						
6				1(8.4%)					1(8.4%)	11(91.6%)
7										
8										1(8.4%)
9										
≥ 10										

In the region of the arms, forearms, and wrists, the score was 2 in 100% of the participants. Precisely, flexion above 20º was indicated for the arms, forearms flexion was above 100º, and wrists flexion was between 0º and 15º. However, in the case of the wrists, one more score was added due to the frequent rotation movements when handling the joysticks, as shown in Figure 5.

Figure 5. Positioning of the wrists

The combinations of these results were compared to the B score table, indicating that 100% of the respondents had a final REBA score of 2. Among the participants, 91.6% had a final REBA score of 6 and were categorized as subject to medium risk and action level 2. The remaining 8.4% of the participants had a final score of 8, categorized as high risk and action level 3, according to Table 2.

3.3. Critical considerations of the operational analysis

This research study investigated potential risks and their relationship with the prevalence of musculoskeletal symptoms in QC operators. The lower back, cervical and neck regions, and wrists and hands showed the highest incidence of musculoskeletal symptom prevalence. However, all other regions showed some percentage of symptom prevalence, indicating the need for interventions in a general way regarding the risk factors of the activity. Figure 5 shows the most affected body regions in the total percentage of pain/discomfort, and it can be observed that the highest incidence was in the lower back (83.33%), cervical (75%), and neck (75%) regions. These percentages agree with the results of the REBA posture analyses, which also indicated higher incidences in the neck, trunk, and wrists regions, as shown in Table 5. In the upper limbs, the wrists and hands also showed a high rate of discomfort that the continuous and prolonged use of the control joysticks might cause.

These results confirmed what was visually observed during the field visits for data collection and photographic records, where the work posture of the operator causes discomfort in the mentioned regions, as shown in Figure 5. In the lower limbs, the biggest complaints were in the right knee (66.66%), followed by the left knee (33.33%) and hip/thighs (16.66%).

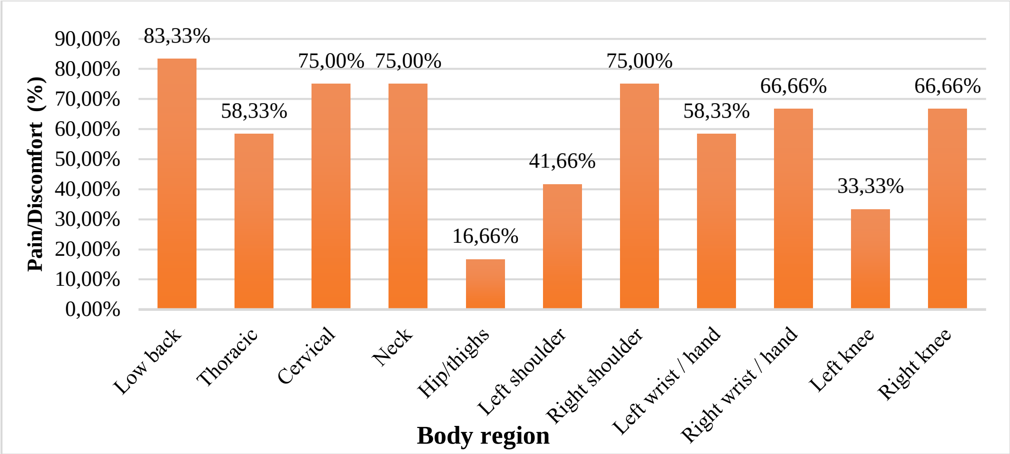


Figure 6. Percentage of Pain/Discomfort by Body Region

Regarding laterality, the right side of the upper and lower limbs had the most discomfort. The results are similar to previous research reports (Nagaraj *et al*., 2019; B. Rathore *et al*., 2020). To our knowledge, no similar information was found in the literature in correlated activities regarding laterality. However, in general terms, the results presented are confirmed based on similar research (Sekkay *et al*., 2018; Kim *et al*., 2016; Mozafari *et al*., 2015; Bovenzi, 2015) with truck drivers who work in relatively similar postures. In these studies, the body regions that showed the most significant discomfort were the lower back, neck, and shoulders, indicating the prevalence of musculoskeletal symptoms also in these professionals. These results are believed to be justified by the high repetitiveness of efforts in the task for long periods, mainly involving tilting the head forward, thus forcing the cervical and the lumbar spine to make the work posture viable. The wrists are also very demanding due to the constant maneuvering of the joysticks and control buttons, leading this region of the body to suffer a high level of discomfort. A potential discomfort factor identified during the field visits was the lack of seat adjustments. These seats have numerous adjustments (backrest, seat, arms, forearms) that minimize the operator's discomfort. However, over time these controls are degraded and go out of operation without receiving maintenance, which contributes significantly to the increase of musculoskeletal symptoms in these professionals working in less comfortable positions. The ABNT NBR ISO 11226 (2013) standard states that pain, fatigue, and musculoskeletal system disorders can result from maintaining inappropriate work postures, which precarious work situations can cause. All these factors influence the absence of workers from their activities due to work accidents, occupational diseases, fatigue, and or stress (SHIDA and BENTO, 2012). Thus, it is crucial and has a high positive economic and health impact on keeping the suitability of the workstations.

The final REBA score revealed that 91.6% of workers were at medium lesion risk, and the remaining 8.4% were at high risk. These numbers, combined with the NMQ results, indicate the prevalence of musculoskeletal symptoms in those workers and the need for further study and ergonomic intervention at the workstation to circumvent the risks of severe injuries and permanent disorders. A current survey also conducted in transportation, in this case, air transport, revealed that 57% of workers were in the high-risk category, showing the need for immediate intervention (ASADI *et al*., 2019).

3.4. Machine learning results

Table 6 presents the training results of the implemented regression models. Models based on logistic regressors showed the lowest values of the MSE metric, indicating in the first analysis better predictions than the other models based on decision trees and linear regressors.

Table 6. Results of Regression

	Regressor	Body region with pain	Mean MSE	MSE Standard deviation	Mean R^2	R^2 Standard deviation
1	Logistic	TG1 – Neck	0.267	0.133	-0.200	0.600
7	Logistic	TG3 – Wrists and hands	0.333	0.211	-0.500	0.949
22	Logistic	TG8 – Hips/thighs	0.350	0.268	-0.388	1.009
19	Logistic	TG7 – Cervical	0.352	0.275	-0.386	1.015
13	Logistic	TG5 – Low back	0.360	0.265	-0.480	1.044

	Regressor	Body region with pain	Mean MSE	MSE Standard deviation	Mean R^2	R^2 Standard deviation
16	Logistic	TG6 – Thoracic	0.367	0.290	-0.417	1.065
4	Logistic	TG2 – Shoulders	0.400	0.200	-0.800	0.900
10	Logistic	TG4 - Knees	0.417	0.255	-0.700	0.992
14	DecisionTree	TG5 – Low back	0.427	0.259	-0.800	1.175
17	DecisionTree	TG6 – Thoracic	0.456	0.251	-0.883	1.145
8	DecisionTree	TG3 – Wrists and hands	0.467	0.237	-0.967	1.072
20	DecisionTree	TG7 – Cervical	0.476	0.243	-0.943	1.120
11	DecisionTree	TG4 - Knees	0.483	0.247	-1.050	1.139
23	DecisionTree	TG8 – Hips/thighs	0.500	0.247	-0.938	1.097
2	DecisionTree	TG1 – Neck	0.600	0.133	-1.300	0.872
5	DecisionTree	TG2 – Shoulders	0.600	0.133	-1.500	0.775
12	Linear	TG5 – Low back	0.944	1.018	-2.640	4.708
6	Linear	TG3 – Wrists and hand	1.019	1.157	-3.115	5.303
15	Linear	TG6 – Thoracic	1.031	1.005	-2.991	4.704
9	Linear	TG4 – Knees	1.073	1.091	-3.279	5.066
18	Linear	TG7 – Cervical	1.125	1.154	-3.364	5.404
21	Linear	TG8 – Hips/thighs	1.147	1.095	-3.340	5.191
3	Linear	TG2 – Shoulders	1.291	1.317	-4.314	6.098
0	Linear	TG1 – Neck	1.688	1.701	-5.599	8.111

This last class of models presented the highest mean prediction errors among them within the models based on logistic regressors. The three best results presented are related to the predictions of TG1 – neck. TG3 - wrists/hands, and TG8 – hips/thighs with mean MSE values of 0.267, 0.333, and 0.350, respectively. However, when we analyze the mean R^2 metric, although the trend of the best and worst models follows the behavior already described above, the values of this metric for all trained models are negative. This result indicates a low fit of the regression models studied regarding the experimental data for training these models. This low fit quality can be explained based on the amount of data obtained from the applied questionnaires. Since the number of individuals interviewed (n=12) resulted in a minimal sample of data, that is, not very representative; the trained models could not identify the behavior of these data, resulting in the low quality of the regression adjustments. However, these results cannot be interpreted as indicating that ML is not applicable to help understand the problem studied but for the proper use of this type of computational tool. The quality of the results is closely linked to the size of the database training. Hence, the more representative the database, the better the predictive power of ML models.

It is necessary to emphasize that these machine-learning techniques have been increasingly used in recent years. The use is related to collected data, classification, and regression techniques to detect accidents, classify diseases, and identify risk factors for accidents in work activities. i.e., the safety of human work operations. as it has been shown in the literature (Attar *et al*.. 2022; dos Reis *et al*.. 2021; Khairuddin *et al*.. 2022; Maheronnaghsh *et al*.. 2021). Specifically, the authors have emphasized the importance and direct and indirect benefits of using Machine Learning techniques in creating expert systems with intelligent behavior to find solutions to complicated problems and, finally, process massive amounts of data related to occupational safety and health (OSH). Therefore, this statement and recommendation of the authors confirm the relevance of the results found in this proposal related to the ergonomics approach to the prevalence of musculoskeletal disorders in quay crane operators.

3.5. Final discussion and recommendations

The object of this research is the reality of the work environment of QC operators in northeastern Brazil, which needs to be modernized, but this is the context of most ports in the world. Operators have several sources of suffering, such as exposure to vibrations and physical fatigue to access increasingly higher QCs which do not always have operational elevators and difficulty going to the restroom. As shown in this research, they work in uncomfortable postures that are proven to cause harmful effects on health.

As a result of numerous research in technology, a new proposal for remote crane operation was implemented in some ports around the world, such as Rotterdam in Holland and the international terminal of Manzanillo in Panama. Figure 7 shows a control room with remote QC operation. It is located in an administrative building far from the pier so that the operator does not need to climb on the crane, nor is he exposed to vibrations. They work in a much more ergonomically comfortable position. In physiologically proper postures, with options of turns working standing or sitting. Also, they are always accompanied by colleagues who can help solve a situation of doubt—additionally, the possibility of an immediate replacement for any need or rest break.

These technologies are only available in approximately 5% of ports worldwide (ABB.2023). The ports that still do not have the remote operation of cranes must improve the workplace conditions of the QC operators since changing to the remote modality is costly and long-term. Rigorous maintenance on the operator's seat is recommended to allow the necessary adjustments in the seat height, backrest, and arms. It would also be helpful to install camera systems with approximation, avoiding forced posture and facilitating the visualization of essential areas for operator maneuvers training and medical monitoring. These are some suggestions for these improvements.

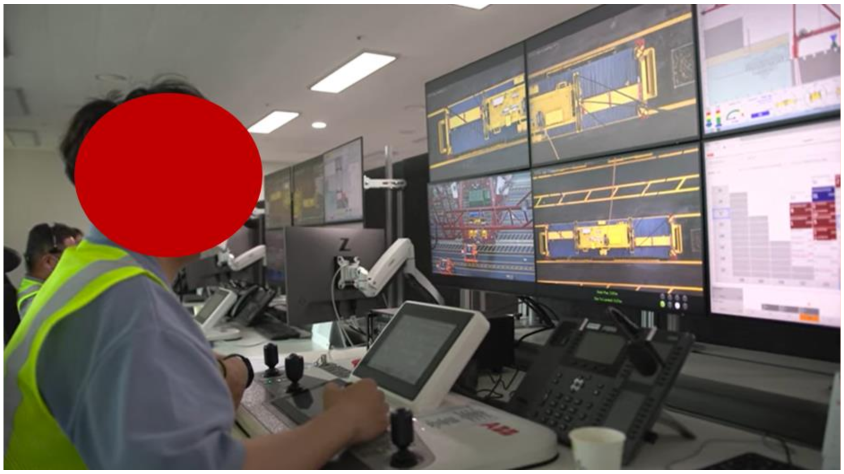


Figure 7. Remote Portainer operating room (ABB. 2023)

Hence. the proposal of the present work: integrating regression models through ML techniques with tests and safety procedures at work activities, has been shown as an additional alternative to identify the relationships between the primary MSDs and possible work conditions associated with port workers who operate these quay cranes.

4. CONCLUSIONS

This research aimed to understand the prevalence of discomfort and pain caused by musculoskeletal symptoms among QC operators. Understanding this prevalence and associated ergonomic risk factors can help develop approaches to ensure safe and healthy working conditions. The results highlighted a high prevalence of musculoskeletal symptoms in the upper and lower body regions suggesting greater attention and the need for ergonomic intervention. The machine learning models used: logistic decision tree and linear ratify these conclusions. Among those ML models, the logistic regression showed the best results for predicting pain in the neck, wrists and hands, hips and thighs, and cervical region.

The study of postures at work through the REBA method revealed a posture with a medium lesion risk factor, resulting from a workstation lacking maintenance and proper gear adjustments, such as height adjustment of the seat and angulation devices for the arms. Forearms, legs, and thorax. These shortcomings can be reduced by effective workstation design and preventive maintenance of seat adjustments. Another intervention to improve the relief of the neck and cervical spine region pains would be to optimize the operator's visual field by installing monitors connected to cameras in the front and top of the cabin. The monitors would show detailed images of the placement of the containers so that the operator would not need to bend down to view through the cabin's glass floor.

Due to the long distances between the cabin and the cargo location, a significant additional benefit for productivity is the possibility to zoom in on the images when more precision is required, such as when placing the container in the limited spaces within the ship. Such a feature would optimize time and increase cargo-handling operations' safety. It is also suspected that the cognitive load sustained by the operator who needs to have a high specialization to maneuver the QC. The pressures for fast operation from the owners who pay for the crane's operational hours and the responsibility for the safety of the operation may be a predictor of musculoskeletal symptoms.

ACKNOWLEDGEMENT

The first author thanks the PPGEM/UFPE for supporting the doctorate course. The authors acknowledge the support from the Brazilian agencies Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brazil (CAPES) - Finance Code 001.

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