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Biomechanical workload during manual lifting: A case study on seaport stevedores in Colombia

Carga física biomecánica durante el levantamiento manual de cargas: un caso de estudio en estibadores portuarios en Colombia

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Abstract

Workload related to material handling is one of main biomechanical risks that cause work related musculoskeletal disorder at work. The aim of this study was to assess the risk factors for biomechanical loading present at carried out tasks by port stevedores. First, we made a diagnosis using the risk assessment matrix (RAM) then; we evaluated the biomechanical risk using the NIOSH lifting equation (Compound method). The results were a high level of unacceptable risk at the beginning and at the end of the task (scored 4.22 and 8.50 respectively). Subsequently, we made a correlation analysis between this scored and the musculoskeletal discomfort perceived by stevedores. From this analysis, it is evident that there is a direct relation between lifting vertical distance, trunk torsion, and the increase of musculoskeletal lesions suffered by the dockers. Finally, we proposed some methods to improve the activities of filling and emptying containers and minimize the manual material handling.

Keywords: seaport stevedores; risk assessment matrix (ram); manual material handling (mmh); lifting index.

Resumen

El manejo manual de materiales es uno de los principales riesgos asociados a la carga física biomecánica que influye en la aparición de los trastornos musculoesqueléticos de origen laboral. El objetivo de este estudio fue evaluar la carga biomecánica presente en las tareas realizadas por los estibadores portuarios. En primera instancia se realizó un diagnóstico usando la matriz de evaluación de riesgos (RAM); y luego se evaluó el riesgo biomecánico usando la ecuación de levantamiento de NIOSH (método de Compuesto). Se detectaron altos niveles de riesgo al inicio y al final de la tarea (valores de 4.22 y 8.50, respectivamente). Posteriormente, se realizó un análisis de correlación entre este puntaje y la incomodidad musculoesquelética percibida por los estibadores. A partir de este análisis, se evidenció que existe una relación directa entre la distancia vertical del objeto, la torsión del tronco y el aumento de las lesiones musculoesqueléticas que sufren los estibadores.

Palabras clave: estibadores; matriz de evaluación de riesgos; manipulación manual de materiales; índice de levantamiento.

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1. Background

In Colombia, seaports have a fundamental role in the development of trade operations. Statistics by the Colombian Ministry of Transport show that over 202 million tons were traded in 2017. This information indicates the importance of this mode of transport for the Colombian economy [1]. Cartagena Port is one of the main national ports where most of the merchandise is handled manually. This activity requires the assessment of factors related to biomechanical physical load to evaluate the risk of musculoskeletal disorders on the workers who carry out these operations [2]. In the operational area are three important jobs: the stevedore, the supervisor and the forklift operator.

In many countries, stevedores have been the object of study related to health issues, welfare and appropriate working conditions. In Spain, for instance, experts in the port area describe the 30 risks that may appear at this workstation, from which we can highlight overexertion, exposure to extreme high temperatures, abuses or impacts with vehicles, fatigue and stress [3]. In Cuba, a study describes the structure, process, and impact of safety program enhancement among stevedores at the port of Havana. The aim of this study is to reduce occupational injury risk and improve safety conditions as well as improving safety. As contrasted with the comparison group, injury incidence decreased in the intervention group, accompanied by significant improvements in safety behavior and injury hazard identification [4]. However, there are a few studies that focus on the issue of manual lifting and consider the ergonomics of the stevedores' workstation although Manual Material Handling (MMH), especially lifting, leads to an increased risk of low back pain [5,6] and others musculoskeletal disorders (MSD).

These risks are mostly triggered of MSDs and they represent an important health problem that distresses a large number of workers, since it does affect not only their welfare, but also represents a significant social and economic cost. This has been stated by governmental organizations, such as the European Agency for Security and Health at Work that affirms in Germany, for instance, the musculoskeletal disorders cause approx. 30% of lost days at work [7]. In terms of disabilities, in a three-month period, the stevedores presented discomfort in low back, shoulders and knees. These disabilities were between 1-7 days (freq. 1 shoulder, 3 low back), 8-30days (1 low back) and more than 30 days (freq. 1 knee). However, in Colombia are rules that determine the frequency and severity of the disabilities related at work. In this is the case, the NTC 3701 specifies the hours lost per every 200,000 hours worked.

The International Labor Organization describes that more than 27% of the work accidents and non-fatal professional diseases that caused days of absenteeism in the United States were due to back problems. According to studies in USA, the total social cost produced by back pain was annually estimated between USD 50.000 and 100.000 million. Furthermore, a 30% of the American workers usually do activities that imply a back pain suffer, and a 50% of them have workstations that may produce cumulative trauma disorders [8]. Similarly, the World Health Organization states that when the body holds heavy loads, the bone structure may be subject to excessive efforts and it may suffer damage. Besides, if someone lifts heavy material for a long time, degenerative disorder may appear, especially on back area [9][10]. This study involves an evaluation of biomechanical workload due to load lifting in a port operator company in Colombia. This factor triggers musculoskeletal discomforts that are reflected on production levels, the increase on absenteeism and the deterioration of life quality of stevedores at work.

The aim of this study is to determine the biomechanical workload due to manual material handling and establish the relationship between this risk factor and the musculoskeletal discomforts present on the stevedores of Seaport Company.

2. Method

This work was an observational and analytical study of case with the purpose of diagnosing and assessing the risk factor for biomechanical workload due to lifting.

2.1. Population description

The sample was determined from a population of 37 stevedores who work at the Port of Cartagena. We calculated the study sample with the following equation

$$n = \frac{NZ^2P(1-P)}{(N-1)e^2 + Z^2P(1-P)} \quad (1)$$

Excluded from the calculation, the stevedores whom were working less than 6 months. Working with a 95% level of confidence and a sampling error of 7 %. We considered a sampling rate of 0.5 that corresponds to the probability of getting sick or not due to the work conditions. Population= 37; Number of stevedores with less than 6 months in the company=9. Finally, 25 stevedores participated on this study and we used this sample to analyze the comfort and discomfort of participants through the Nordic questionnaire.

2.2. Procedure

We applied an ergonomic evaluation methods, technical tools and instruments to analyze each phase of this research. Musculoskeletal disorders were assessed using the results of a technical test made by a Labor Risk Manager (ARL in Spanish), which offers this kind of services to the company. Next, we used the Risk Assessment Matrix (RAM) as a diagnostic tool to analyze the working conditions related to other elements of the company.

There are several methods for assessing manual handling of loads [11]. The NIOSH lifting equation has established that these methods depend on the complexity of the task. Therefore, initial way that the researchers used were the simple version of the method. However, due to the characteristics of the task, we included the complex version to obtain a result that fits the reality presented in these kinds of companies. We measured with instruments such as tape and protractor of 360º to obtain the variables contemplated in this method at different heights to evaluate subsequently the risk factor in each state.

Likewise, to satisfy the criteria of relative humidity and temperature established by NIOSH, the metabolic consumption of stevedores was determined corresponding to the activity components. According to the National Institute for Occupational Safety and Health at Work in Spain, NTP 323 is one of the most common industrial systems used to determine metabolic consumption because it contains separate information about postures, positions and movements to obtain the energy expenditure of every single component, and generate the integral metabolic consumption for the whole task.

Finally, to establish the relation between the risk factor and the musculoskeletal discomforts presented on the stevedores, we used a survey to determinate the musculoskeletal discomfort intensity. We applied this survey to stevedores who were doing the task having as a model the Nordic questionnaire format [12] and Borg's subjective scale as a numerical scale of intensities. We processed the obtained data through SPSS® and Statgraphics software®.

2.3. Assessment Intruments

2.3.1. RAM Matrix

We used the RAM Matrix to evaluate the working conditions. It also determined the incidence of risk for the categories: people, economic impact, environment, customer and company's image; it was taking into account historical evidences and experiences inside the organization. [13]. The results were related to musculoskeletal evaluation made to thirty company workers by the Labor Risk Manager (ARL), this report was taken as inputs to proceed for the assessment of symptomatic conditions. In order, Scoliosis with 12 appearances, Muscles spams with 6 appearances and Low back pain / Arthralgia of the ankles with 4 appearances were the most MSD reported during the study period. We assessed these conditions through RAM Matrix considering the consequences and probability established by the matrix, following this sequence:

- The real consequences derived from each condition for the categories people, economical, customer and company's image, were determined based on clinical reports.
- It was calculated the corresponding intersection point between the consequence and the probability, in order to obtain the risk assessment (N=none, L=low, M=medium, H=high, VH=very high).
- We repeated this process for every condition analyzed.

2.3.2. The NIOSH equation

We evaluated the Lifting load by NIOSH equation. The application of the method on its simple version was not accurate enough; due to it had contemplated different levels of height and depth when they lifted the objects. Moreover, due to the different weights of items, it was necessary the calculation of the increase of the cumulative risk to the task of greater simple index (ΔILTi). For these characteristics, the NIOSH method used was the compound method [14].

Every height level at the origin was established as a task. We generated these levels as the forklift took and placed them on the previous stowage that had been already unoccupied. According to this, it was determined the different height points on a stowage, so for each tasks components of the process, the NIOSH compound method was applied. We made the measures of each one in the filling process of a cargo container with kegs of 21.2 kg. This was including into the protocol for the measurement of each one of these variables. Once the measurements were done, we calculated the factors of the NIOSH equation for the origin and destination point. The product of these factors gave as a result the recommended weight limit, the lifting conditions and the simple lifting index for each one of the tasks. The activity was realized by the stevedores obeys a compound task, so the application of the NIOSH method on its simple version was not accurate enough. After, the researchers

proceeded with the calculations when it comes about a compound task indicated by the method.

We sorted the indexes of simple lifting from highest to lowest for both the origin and destination. Then, we calculated the increase of cumulative risk to the task of greater simple index (ΔILTi) and the compound lifting indexes (origin and destination) through the sum of the highest simple lifting indexes (ILT1) and the increase of the accumulated risk. Finally, we measured the metabolic consumption of the stevedore's workstation indirectly in order to determine the incidence of caloric expenditure in occurrence of musculoskeletal lesions related of biomechanical workload.

2.3.3. RAM Matrix Relationship between the risk factor and musculoskeletal discomforts

To establish the relationship between the risk factor and the musculoskeletal discomforts, we utilized a comfort discomfort survey to the stevedores who participated in the task evaluation. This, with the purpose of identifying which were the measures of the discomforts generated on every origin and destination point of the lifting, when the task was realized. In the Nordic questionnaire, we asked about the discomforts on neck, shoulders, and low back, since these body areas generate more discomforts on stevedores according to the risk assessment obtained from the RAM matrix. The survey results was evaluated in order to determine if they had a normal behavior, since to measure the correlation between two variables, both should have a normal distribution in the population where the sample comes from.

3. Results

Below is the main activities that stevedores perform in their shift work, the handling of heavy objects in one of the most common tasks (See Figure 1). Regarding the results of the analysis of comfort by Nordic questionnaire, we found that the total respondent's stevedores have or have ever submitted musculoskeletal discomfort attributed to the positions and work-related efforts. As noted, stevedores have discomfort in most areas of their body. Among the most common complaints, include those located in the lower back (68%), neck (56%) and shoulders (48%) (See Figure 2).

3.1. Assessment of musculoskeletal conditions - RAM Matrix

Scoliosis has caused minor lesions on the stevedores and has affected the image of the company at Cartagena's Port Society. However, this has not brought significant economic consequences, and equally it has not had neither positive nor negative impact on the customers' perception. According to the results of RAM matrix, the researchers found that stevedores have the risk to suffer scoliosis level 2, low grade. For this reason, improvements should be made in the already established control systems. Regarding the induction plans, procedures and work instructions; a better operative steps sequence should be established to realize the activities in a safe way.

Figure 1. Tasks developed by stevedores

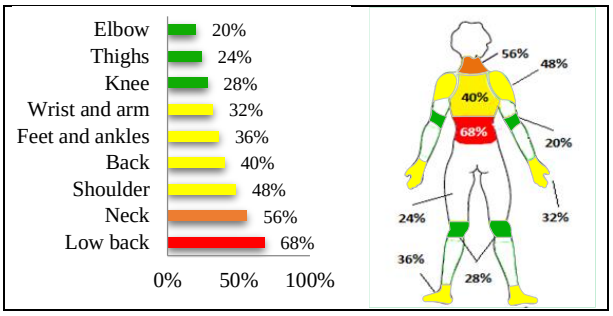

Figure 2. Most common musculoskeletal complaints in stevedores

This condition related with muscle spasms is very common on the stevedores due to the large amount of physical activity that they do on their regular working tasks. The muscular spasms that have presented on these workers have caused minor lesions, which have required first aid. However, this has not lead to significant economic consequences, neither has affected negatively or positively the worker's perception.

The result indicates that the risk level that the stevedores have for suffering muscles spasms when they are working is level 1, low grade. At the same time, the neck pain is a frequent discomfort suffered by stevedores who work at Cartagena's Port Society (Target population). Thus, this has not had a bad impact neither in the economic area nor in the customer's perception.

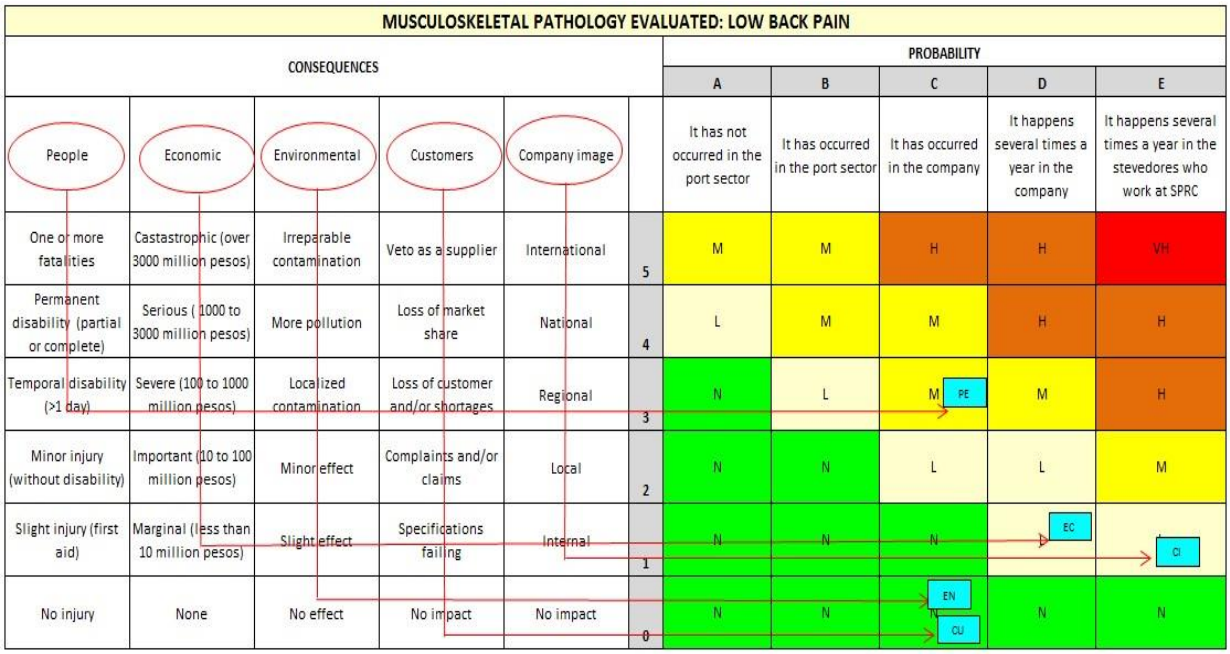

Figure 3. Tasks developed by stevedores

However, the inside perception the company has been affected. The risk level of suffering neck pain was level 2, low, which relate the efforts done by these workers when they realize their activities (See Figure 3).

The back pain has been presented, generating some sick leaves for longer than a day, which is reflected on a marginal economic impact, but significant for the company. Even though this pathological condition has not generated any positive or negative impact on the customers, it really has affected the inside company's environment in terms of the worker's motivation to develop new activities. The risk level of suffering low back pain because of the bad posture habits, heavy physical works, trunk rotation movements, among others, was level 3, medium grade, which means that the established control systems are not enough.

It is important to mention that back pain, besides being presented in several cases in the company in study, it was also presented in a particular case, which influenced directly in the assessment of this condition (risk level 3). This case is about a stevedore who was diagnosed with a chronic back pain syndrome for intervertebral disc disorders due to important exposure to ergonomic risk at his working activity. For the importance of the diagnosis and the continuous extensions of sick leaves for this worker, losing of working capacity is considered, which may increase the assessment grade of this pathological condition. Due to Low back pain is the condition with the highest risk level, it was established a theoretical relationship with the risk factor for biomechanical physical load due to load lifting.

3.2. Relationship between biomechanical physical workload and the musculoskeletal discomfort on the lower back

According to the National Institute of Security and Health at Work, the musculoskeletal disorder on the low back area usually appears on people who are subject to carry continuous overload on their backs [15]. Furthermore, it is claimed that back pain may also be caused by an intense trauma such as an accident or an important muscular effort where soft and hard structures of the spine may result injured. Generally, the back pain is a symptom that may be the consequence of multiple causes. However, the components pertaining to the risk factor by load lifting such as strength (weight of load), the distance of origin and destination of the load, and physical and nutrition conditions are the main causes that influence on the appearance of this discomfort.

In this company, these factors are evident on the tasks performed by stevedores since these tasks are characterized by manual handling of heavy loads.

Likewise, the professional risk manager, on their epidemiologic surveillance system for the prevention and control of back pain, states that the main associated factors with this discomfort are the action of lifting, holding and transporting objects especially when such handling is often done manually and with objects that exceed the limit of the workers' capacities.

3.3. Assessment of the risk factor by load lifting – NIOSH equation

3.3.1. Determination of lifting indexes

The table 1 shows the horizontal and vertical distances on the origin and destination points are higher than the ideal figures to lift a load. It should be noted that in most of the tasks, there is a good grasp, which is considered positive in this activity. At the same time, it shows the results of the NIOSH method (simple version) on the origin and destination points for each task that integrates the global activity. This is the first stage of the NIOSH method application for compound task (H in origin is 27cm).

After, the multipliers of each task were compared on the origin and destination points, and it was concluded that corrective measures must be applied at the destination point, especially on the horizontal distance and vertical position of the load since they are the figures closer to zero (0). This means that they are far from the ideal measures (25cm y 75cm for H and V respectively) when it comes to handle a load. In addition, the researchers observed that the real weight of load exceeds the limits of recommended weight (RWL) for the height and depth points at destination, which means that stevedores do too much physical effort when they are leaving the load. The results of the second stage are shown on table 2 where the index of compound lifting was 4.22. This data indicates a high and unacceptable risk level, so the literature recommends a redesign of the workplace immediately. Likewise, it is shown that the lifting index for destination was 8.50, overtaking by more than 50% the compound-lifting index at the origin, which means that at the destination point, there is also a high and unacceptable risk level. This confirms the severity of the risk factor by load lifting on these tasks.

3.3.2. Determination of energy expenditure

The metabolic consumption was nearly 8.52 kcal min-1, which indicates that these workers are more prone to suffer muscle lesions, especially on the back area, since their metabolic consumption exceeds 4.17 kcal min-1, which is the recommended figure of energy consumption by ergonomic methods. This means that environmental variables (temperature and humidity) increase the consequences derived from the load lifting risk factor (See Table 3).

As it is observed, the stevedores have a high physical load in trunk and arms (without considering a basal metabolism) of approximately 7.38kcal min-1. In comparison with other studies related to metabolic expenditure [16-19], only some jobs such as carrying load with shoulder straps (20% gradient) exceed the metabolic cost derived from this work [20,21].

Table 1. Results NIOSH Equation manual lifting

Task	General		Origin				Destiny				
	F	D	V	A	RWL	LI	H	V	A	RWL	LI
1	3,48	0,07	87	30	15,1	1,41	31	152	12	11,1	1,90
2	2,61	0,10	58	60	12,9	1,65	31	152	12	11,4	1,86
3	2,87	0,09	101	30	14,8	1,43	58	190	12	5,2	4,07
4	1,58	0,16	72	60	14,5	1,46	58	190	12	5,3	3,99
5	1,89	0,13	116	30	14,7	1,44	58	190	12	5,5	3,89
6	1,27	0,20	79	60	15,0	1,42	58	190	12	5,5	3,85

F= Frequency (t/min); D=Duration (hours); C=Coupling; H=Horizontal; V=Vertical; A= Asymmetry.
Source: The authors

Table 2. Calculations of compound lifting indexes in origin and destination

Compound Lifting Indexes		Origin	Destiny
1	FM(F1)	0,88	0,88
	RWLT2(F1)	13,99	5,14
	LIT2(F1)	1,51	4,12
2	FM(F1+F2)	0,84	0,8
	RWLT2(F1+F2)	13,36	4,67
	LIT2(F1+F2)	1,59	4,54
3	FM(F1+F2+F3)	0,75	0,7
	RWLT3(F1+F2+F3)	12,16	4,20
	LIT3(F1+F2+F3)	1,74	5,05
	RWLT3(F1+F2)	13,61	4,80
	LIT3(F1+F2)	1,56	4,42
4	FM(F1+F2+F3+F4)	0,6	0,6
	RWLT4(F1+F2+F3+F4)	10,85	3,52
	LIT4(F1+F2+F3+F4)	1,95	6,03
	RWLT4(F1+F2+F3)	13,56	4,10
	LIT4(F1+F2+F3)	1,56	5,16
5	FM(F1+F2+F3+F4+F5)	0,45	0,41
	RWLT5(F1+F2+F3+F4+F5)	7,17	5,43
	LIT5(F1+F2+F3+F4+F5)	2,95	3,9
	RWLT5(F1+F2+F3+F4)	9,57	7,95
	LIT5(F1+F2+F3+F4)	2,22	2,67
6	FM(F1+F2+F3+F4+F5+F6)	0,31	0,31
	RWLT6(F1+F2+F3+F4+F5+F6)	5,57	4,01
	LIT6(F1+F2+F3+F4+F5+F6)	3,81	5,29
	RWLT6(F1+F2+F3+F4+F5)	8	5
	LIT6(F1+F2+F3+F4+F5)	2,62	4
	CLI	**4,22**	**8,5**

3.4. Relationship between the risk factor for biomechanical physical load due to load lifting and musculoskeletal discomforts

According to the survey's results, the low back zone presented a greater intensity discomfort when the height at the origin is too low and the height at destination point is too high. There are also discomforts when the workers have to twist more than 60°. Normal test was determinate applying the non-parametrical test of Shapiro Wilks for samples with less than 30 items.

The null hypothesis established Ho: The data set follows a normal distribution. From this hypothesis, it was carried out a correlation analysis between variables (variables of NIOSH equation such as vertical and horizontal distance, and the intensities of musculoskeletal discomforts according to the subjective scale of Borg) to determine the existence of a lineal relationship among them and calculate the Pearson's correlation coefficient [22].

According to Shapiro Wilks P figures, we concluded that the data set of discomforts intensities on the neck (0,37), shoulders (0,09) and low back (0,11) followed a normal distribution since this P figure is greater than 0.05, so the null hypothesis presented recently is accepted. We showed the results of the correlation analysis between the variables on Table 4.

Table 3. Stevedore's energy cost and their comparison with other studies

Energy cost of a stevedores (kcal min $^{-1}$)	
Basal metabolism	1.14
Postural component	
Standing	0.65
Inclined standing	0.78
Component of the type of work	
Work with two arms	4.01
Work with the body	1.94
Total energy cost (without basal metabolism)	**7.38**

Comparison of energy costs			
Activities	(kcal min $^{-1}$)	**Author**	**Year**
Stevedores	7.38	Present study	2018
Lifting car by jack	4.5	Passmore and Durnin	1955
Carrying load with shoulder straps (20% gradient)	8.5	Das and Saha	1966
Carry H-blocks	2.34	Almero	1984
Carrying box (8–12kg)	4.90	Almero	1984
Carry load (20kg)	3.42	Samanta	1987
Picking handling a basket (12kg)	4.58	Costa et al.	1989

Source: The authors

The risk factor by lifting load and musculoskeletal discomforts show that with a confident level of 95%, the displacement variable has a positive relationship with the discomforts on neck and low back, and the asymmetry angle variable has a positive relationship with the neck discomfort since the Pearson coefficient is between zero and one.

Table 4. Correlation analysis

		NECK	**SHOULDER**	**LOWBACK**
Vo	Pearson Correlation	-.907	-.770	-.897
	Sig. (2-tailed)	.000	.003	.000
	Sum of Sq and Cross-products	-320.333	-582.667	-572.500
	N	12	12	12
Vd	Pearson Correlation	-.607	-.035	-.268
	Sig. (2-tailed)	.036	.913	.399
	Sum of Sq and Cross-products	-200.000	-25.000	-187.500
	N	12	12	12
Hd	Pearson Correlation	-.607	-.035	-.268
	Sig. (2-tailed)	.036	.913	.399
	Sum of Sq and Cross-products	-144.000	-18.000	-135.000
	N	12	12	12
Ao	Pearson Correlation	.698	.852	.885
	Sig. (2-tailed)	.012	.000	.000
	Sum of Sq and Cross-products	195.000	510.000	525.000
	N	12	12	12
F	Pearson Correlation	.052	-.423	-.308
	Sig. (2-tailed)	.873	.171	.330
	Sum of Sq and Cross-products	.743	-12.993	-9.380
	N	12	12	12
D	Pearson Correlation	.349	.755	.663
	Sig. (2-tailed)	.266	.005	.019
	Sum of Sq and Cross-products	120.333	557.667	485.000
	N	12	12	12

This means that the greater the vertical displacement with the load is, the greater the intensity of discomforts on neck and low back is. Likewise, the greater the torsion angle is, the greater the intensity on neck discomforts is. For this reason, vertical displacements and large torsion angles of the trunk must be decreased when lifting the load in order to minimize neck and low back discomforts.

4. Conclusions

The achievement of the aim of this study is reflected on the results of the assessment of the risk factor for biomechanical physical load due to load lifting. From the results, we concluded that the stevedores of the participating company are exposed to high levels of risk of suffering musculoskeletal disorders such as scoliosis, cervical and back pain. These disorders are derived from the existence of the risk factor for biomechanical physical load due to load lifting, which is found at a high and unacceptable risk level. For this reason, the literature recommends a redesign of the load or the task immediately.

In addition, the researchers conclude that the variables of this risk factor have direct incidence with discomforts on neck, back and shoulders. For instance, the large vertical displacements and the large torsion angles of the trunk when they are lifting are the critical variables that need to be modified at the origin and destination points.

Otherwise, for the port stevedores was important to know that the risk factor for biomechanical physical load due to load lifting is one of the main causes of musculoskeletal discomforts they suffer daily. As being the stevedores conscious of it, they explored different techniques of manual handling of loads, which mitigated the occurrence of musculoskeletal disorders.

Finally, for a future work, it is necessary to include a job of physiological physical load through the assessment of oxygen consumption, so as to determine whether the proper activities of the task meets the physiological requirements established by the international literature. Likewise, it is important to review the frequency and complexity of the task in order to review the rest of the biomechanical factors present in the port stevedores' tasks.

Furthermore, the researchers implement a procedure for filling and emptying the container that is attended with some existing and purchased equipment that was necessary to provide the solution to the case of study. In the following figure (See Figure 3) an example of two sequences that are part of the proposed procedure are shown.

At the left side of the figure is an alternative to place a ramp in the container to help the forklift to enter until the end of the container and deposit or collect the products. At the right of the figure are presented another alternative that is on the same ramp and a lift table that allows the collection of the products on a massive scale to help the worker to minimize the repetitions of the task. The alternatives were chosen according to the characteristics of the container and the use of the forklift to perform a task that previously did not.

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