Using ergonomic digital human modeling in evaluation of workplace design and prevention of occupational hazards onboard fishing vessel

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ABSTRACT

This paper seeks to present methods for improving the occupational health and safety of Spanish fishermen, and for redesigning the workplace onboard small fishing vessels. To achieve its objective, the research project was designed in four steps: First, the equipment and procedures for catching, handling, and storing fish was studied. Second, the work postures of all the fishermen were simulated and assessed by using an ergonomic digital human modeling system (ManneQuin Pro). Third, the work environment design on board vessels was modified on the basis of acceptable simulated work postures to prevent repetitive movements and lower back biomechanical stresses. In the fourth and final step, ergonomic design parameters were provided to vessel designers.

Keywords

Occupational health and safety, risk factors, vessel ergonomic design, postures simulation, work space, digital human modeling

INTRODUCTION

Fishing is one of the most dangerous professions. According to EUROSTAT, the risk of an accident in the fishing sector is 2.4 times greater than the average for all EU industry sectors. [1]. Working in a difficult environment with long and irregular shifts can increase the range, likelihood, or severity of work-related illnesses and accidents. On fishing vessels, accidents may arise from exposure to dangerous machinery on board as well as from handling catch and tackle. It is easy to overlook health risks in fishing as there are so many potential causes of accidents [2]. The prevention of occupational accidents and illnesses on board fishing vessels has focused on risk assessment and management, training and on-board instruction for fisherman**.** [3]. The continuous assessment of back stress methodology was used to develop distributions describing the amount of time that each of the crew members on a two- or three-man crabbing crew spend at various levels of low back stress [4]. The purpose of the study is to quantify biomechanical stresses on the lumbar spine during work activities of commercial carb fishermen, and thus determine work task priorities for ergonomic intervention**.**

Work-related musculoskeletal disorders and injuries occur when there is a mismatch between the physical requirements and the physical capacity of the human body [5]. Consequently, work related musculoskeletal disorders and injuries are caused by a combination of factors such as repetitive motion, excessive physical exertion, bad and/or awkward postures when working on board of fishing vessels, including lower back pain, upper limb pain, etc.

The main goal of our research is to identify the risk factors in fishing tasks, and to evaluate the workplace design on board *in-shore fishing vessels*. There are many challenges to solving problems of safety and working conditions on board fishing vessels. In our case, there are three main research problems which have to be solved: (1) ergonomics analyses related to workplace layout, and manual lifting and handling; (2) equipment and procedures for catching, handling, and storing fish and other marine resources; (3) workplace redesigning and construction to prevent occupational safety and health problems onboard fishing vessels.

Integration of the human factor and ergonomics in the design and construction of fishing vessels has been studied by many research groups [6] [7]. For instance, personnel movement simulation has been integrated into preliminary ship designing for testing vessel layout suitability. [8]. The project lead to improved ship design; provided a major saving for ship operators; improved the efficiency of the ship designing process by reducing time and costs; and ensured that the vessel was safer and more efficient for the personnel on board. On the other hand, ergonomics research related to workstation layouts, and manual lifting and handling has been implemented in many industrial countries. A structured job analysis procedure was developed to assist occupational health and safety professionals in the recognition and evaluation of exposures to ergonomic stresses in the workplace [9]. Additionally, a comparison of occupational injury in the French sea fishing industry in the 1980s and today was carried out [10]. This research found that catch processing and handling caused a great number of accidents. During these tasks, fishermen have to cope with two main risks: getting cut or pricked, and making an excessive physical effort and/or awkward movement.

Digital human modeling has been applied in ergonomics design and analyses for a long time. A method for conducting workplace assessments in the digital environment was proposed for preventing work-related musculoskeletal disorders [11]. By integrating dynamic simulation and ergonomics evaluation, digital human modeling enables the system designer to visualize and improve workplace design in the digital space. The method has been applied to evaluate automobile assembly tasks. The distinct advantages of integrating the ergonomic analysis model with the digital human modeling include the ability to perform ergonomic assessments in the early design process, and *improved communication of both ergonomic concerns and design alternatives*. A comparative study was made of digital human modeling simulation results and their outcomes in the real world [12]. The results of study show that ergonomic digital human modeling tools (EDHM-tools) are useful for providing designs of standing and unconstrained working postures. However, even it is time- and cost- saving, using EDHM-tool to simulate work processes and postures for purposes of risk prevention has not been adequately done.

This paper is aimed at presenting methods for improving health and safety in the Spanish fishing sector, where occupational hazards rates are extremely high. To obtain its objective, the research project was designed into the following steps: First of all, equipment and procedures for catching, handling, storage and processing of fish have been studied. Second, the work postures of all the fish men have been simulated and evaluated by using a digital human modeling system (ManneQuin PRO, in using by the Lab. of CERpIE, UPC). Third, based on acceptable work postures of fishermen simulated by ManneQuin PRO, the modification of vessel design and construction relevant to the prevention of low back biomechanical stresses and repetitive movements has been recommended. The digital human modeling system applied in this project has been very effective in terms of simulating and evaluating fishermen work postures, and providing ergonomic design parameters for fishing vessel designers.

METHODS

Manual handling involves the movement of heavy loads by hand or bodily force, and should be avoided where possible. Work-related upper limb disorders arise mainly from performing repetitive actions. If this is not possible, risk of injury must be reduced as much as possible by actions that include: 1) Improving workplace design so that less movement is needed; 2) Modifying the load by making it lighter or easier to hold; 3) Training workers in good practices such as proper handling techniques [13].

In order to improve onboard workplace design, one must first simulate the work process and the work postures of the fishermen. Figure 1 depicts the work floating chat for the ergonomic redesign of the workplace on board fishing vessels.

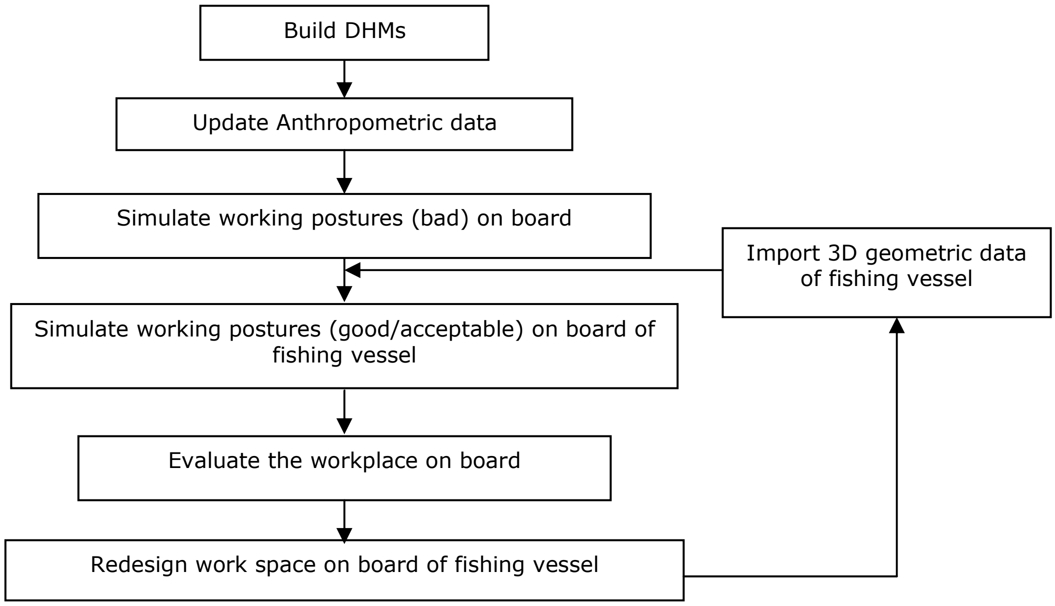


Figure 1 Work floating chat of ergonomic redesign of workplace on board fishing vessel

In this research study, the digital fishermen have been built with ManneQuin PRO. ManneQuin PRO human modeling programs have been the most successful in the world, with thousands of users since the original ManneQuin program was introduced in 1990. Two important features of ManneQuin Pro are: 1)ergonomically correct human figures for a range of ethnic groups, percentiles and body types; and 2) simulation of lifting, pushing and pulling by adding forces and torque in any direction on any body part.

ManneQuin PRO is a PC-based, 3D human modeling software package that helps perform basic analysis during the design, validation, and communication stages of any space design project. It features various biomechanical tools that may be used to enhance analyses or validate new or existing human interfaced designs. Moreover, ManneQuin PRO is conveniently equipped with the Revised NIOSH Lifting Equation for lifting task analysis. If properly used, this formulation can provide a recommended lifting weight for a specified activity. The multiple anthropometric databases for creating mannequins ensure that the space fits the desired population characteristics.

Risk identification and assessment of working on board shipping vessels

The first step of our research was to identify and assess risks in working on board fishing vessels, based on videos and images provided by reporters on board. The hazard parameters and the cause of the parameters of all the working postures including postures of catching, pushing, lifting, pulling, etc. were identified and assessed.

There are several fishing methods for in-shore fishing vessels. Purse seining is the general method of encircling a school of fish with a large net. The net is then drawn together underneath the fish (pursed) so that they are completely surrounded. It is one of the most aggressive methods of fishing and aims to capture large, dense shoals of mobile fish such as tuna, mackerel and herring [14]. Figure 2 describes the steps used in purse seine fishing.

Figure 2 depicts purse seining fishing method

In purse seine fishing inshore, the following tasks are executed:

1. Pull the net through the water to make a type of wall.
2. Gather up the net.
3. With scoop nets, place fish into boxes.
4. Arrange fish into empty boxes until boxes are full.
5. Place ice on fish.
6. Collect fish from the floor and place fish into boxes.
7. Carry boxes to pallet and stack.
8. Lower boxes from ship at port.

Figure 3 explains the typical hazard postures on board fishing vessels found in the analysis: Trunk bending (forward, backward, and sideways); twisting (lower back and lower extremities); and upper arm posture - EN 1005-4: 2002 (E). Figure 4 describes some examples found on board small fishing vessels of workplaces and tasks with high occupational risks. In Figure 4a, the fishermen place empty boxes (for the incoming fish) on top of the full boxes. Figure 4b shows how, after placing the fish in the boxes, the fishermen must squat on the floor in order to pick up the remaining fish on the floor and put them in the boxes. This squatting posture is completely forbidden according to ISO standards. Figure 4c presents the fisherman manually carrying and stacking boxes one on top of the other. Table 1 depicts the risk factors for each of these three tasks.

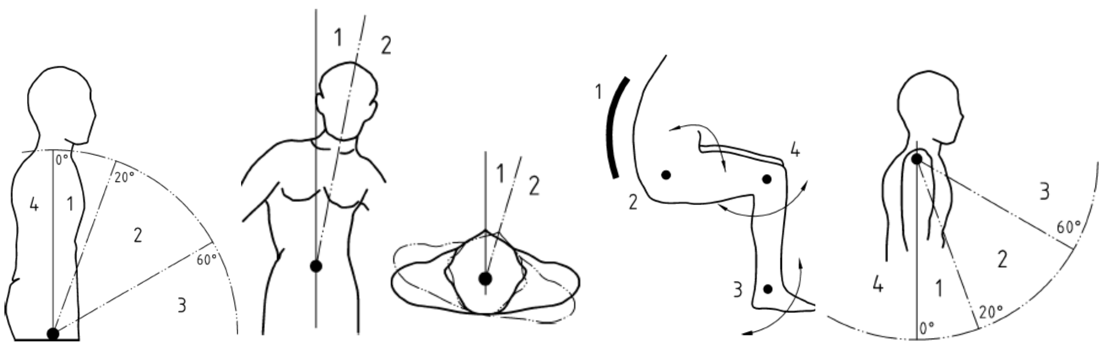


Figure 3 Typical hazardous postures on board of fishing vessels: Trunk bending forward/backward; sideways; twisting; low back and lower extremities and upper arm posture - EN 1005-4:2002(E)

(a)
(b)
(c)

Figure 4 Examples of occupational risks in workplace and tasks onboard small size fishing vessels

Table 1 identification risks from working postures

Task a Arrange the fish inside the boxes		**Task b Pick up the fish from the floor**		**Task c Carry the boxes for stacking**	
Range critical for 5%	**Range critical for 95%**	**Range critical for 5%**	**Range critical for 95%**	**Range critical for 5%**	**Range critical for 95%**
high frequency over 60°	high frequency over 60°	Squat to work	Squat to work	Flexion of the torso 48°	Flexion of the torso 57°
Flexion of the torso between 20° and 60° in high frequency and over 60° is NOT ACCEPTABLE	Flexion of the torso between 20° and 60° in high frequency and over 60° is NOT ACCEPTABLE	FORBIDDEN	FORBIDDEN	Flexion of the torso between 20° and 60° in high frequency is NOT ACCEPTABLE	Flexion of the torso between 20° and 60° in high frequency is NOT ACCEPTABLE
Flexion of the upper arm 89°	Flexion of the upper arm 97°			Flexion of the upper arm 90°	Flexion of the upper arm 97°
NOT ACCEPTABLE	NOT ACCEPTABLE			Flexion of upper arm in 80° with high frequency in moving is NOT ACCEPTABLE	Flexion of upper arm in 80° with high frequency in moving is NOT ACCEPTABLE

Simulation of bad and acceptable working postures

After identifying risk factors, the next step is to simulate bad working postures and present acceptable working postures, with the help of our digital fishermen. The practical limit of arm reach, for example, is not the sole consequence of arm length; the limit is also affected by shoulder movement, partial trunk rotation, possible bending of the back, and the function to be performed by the hand [15]. Therefore, it is difficult to simulate all the possible interactions by various body segments of the men while they are fishing.

The multiple anthropometric databases for creating mannequins ensure that the space fits the desired population characteristics. 5% and 95% percentiles of Spanish fishermen have been selected for simulation in this project. According to statistics in December 2007, there are 50,309 fishermen in Spain. [16]. Among these fishermen, 4% are women. The anthropometric data of the ergonomics software (ManneQuin Pro) has been semi-updated. In other words, only weight and height in the original anthropometry data were updated to the ones of Spanish fishermen.

Other biomechanical and anthropometric data were updated according to these two parameters. During simulation of working postures, differences in degree of physical effort due to variations in body heights are noted, in order better to describe actual conditions for different- sized workers working in the same workplace.

Inputting 3D geometric data of designed fishing vessel into ManneQuin Pro

3D geometric data of designed fishing vessel have been imported into ManneQuin Pro, and all the digital fishermen placed in a 3D fishing vessel in order to simulate real-life work conditions on board.

RESULTS

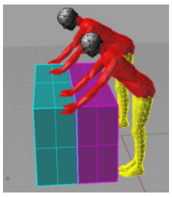
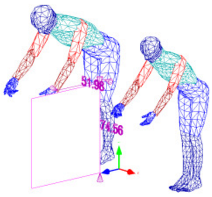
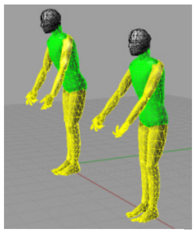
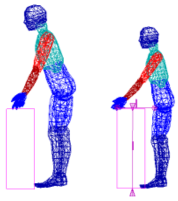
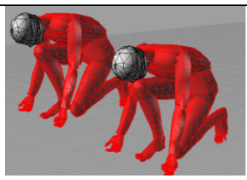
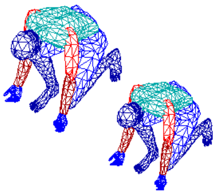
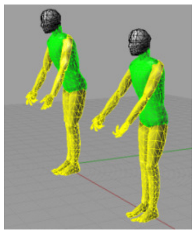
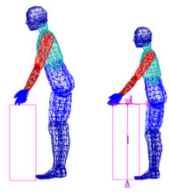
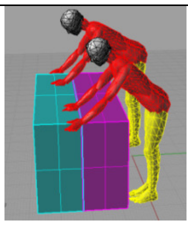
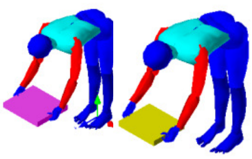
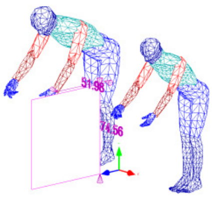
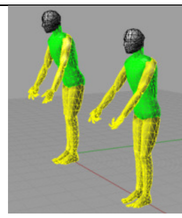
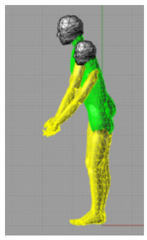
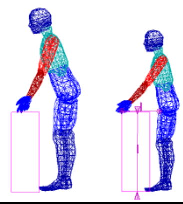
By using an ergonomic digital human modeling system and simulating all onboard work postures, we found multiple risk factors on board fishing vessels. On the other hand, we also found solutions for redesigning the workplace on board to prevent occupational hazards in fish collection, processing, transportation, and storage.

Redesigning work space on board shipping vessels based on acceptable working postures

In this paper we present our research findings in the following tables. Table 2 presents the findings of our analysis of three tasks on board small fishing vessels. Task A is to arrange the fish in boxes until the boxes are full. Task B is to collect the fishes from the floor and put them into the boxes; and Task C is to transport and stack boxes on pallets.

As we can see from Task C, the ergonomic digital fishermen have been simulated in bad postures when transporting and stacking boxes on pallets; accordingly, the upper body-- including the upper arm and neck-- is in hazard red. After analysis of risk factors, solutions for workplace redesign are provided with regard to work surface height. Acceptable and good postures have also been simulated based on the redesigned workplace.

Table 2 depicts the finding of analysis using ergonomic digital human modeling in simulation of three tasks on board small size fishing vessels

Tasks	Digital human modelings (DHMs) in bad postures	Risk factors	Solutions by redesign work space	Parameters of the DHMs in acceptable postures	DHMs in acceptable posture and maximum reach posture
Task a Arrange the fishes inside the boxes until they are full	 	Trunk flexion> 60 º in high frequency. Elbow: flexion and extension movements for more than half the cycle time. Shoulder: arms in extension and abduction for 15% of cycle time.	Work desk height Depth of the working plane	Height of work desk 75cm Depth of work desk 35cm Space for feet (feet clearance)	 
Task b Collect the fishes from the floor and fill them into the boxes	 	Trunk flexion between 20 º and 60 º at high frequency. Lateral tilt of trunk> 10 º at high frequency. Torque of trunk> 10 º at high frequency. Static awkward postures (kneeling)	Work desk height Depth of the working plane Suggest to redesign the collection system avoiding manual operation	Height of work desk 75cm Depth of work desk 35cm Space for feet (feet clearance)	 
Task c Transport and stack boxes on pallets	  	Location initial vertical: the original height of less than 75 cm grip. Vertical Situation final gripping the initial height of less than 75 cm. Horizontal distance: greater than 25 cm. Deflection angle: 45°.	Work desk height, handling should be done from a height between 75cm and 125cm. Depth of the working plane, the horizontal distance of discharge should be less than 25cm. Palletizing system with adjustable platform height. Suggest to use devices for helping the transporting and stack the boxes.	Height of work desk 75cm Depth of work desk 35cm Space for feet (feet clearance)	  

Recommendation for ergonomics workplace design

In our simulation of the workplace on board fishing vessels, we found that there was inadequate foot clearance in the current workplace when fish boxes were being stacked. However, foot clearance is a very important design parameter if fishermen are to maintain good working postures. Therefore, we have made some recommendations in connection with the design of the workplace on board fishing vessels. Figure 5 shows the amount of foot clearance fishermen need in order to maintain acceptable working postures while selecting fish. Figure 6 shows how the workplace can be designed so as to avoid the need to pick up fish from the floor. With this design, the fish will fall directly into the boxes and not onto the floor.

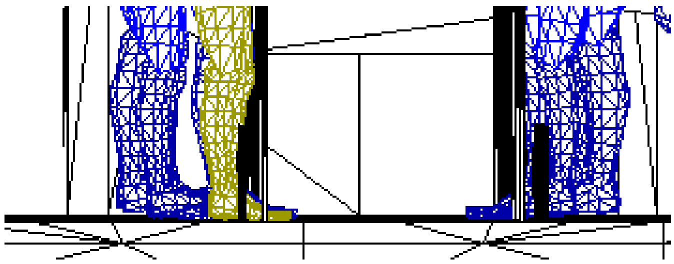


Figure 5 Foot space workers need in order to maintain acceptable working postures when selecting fish

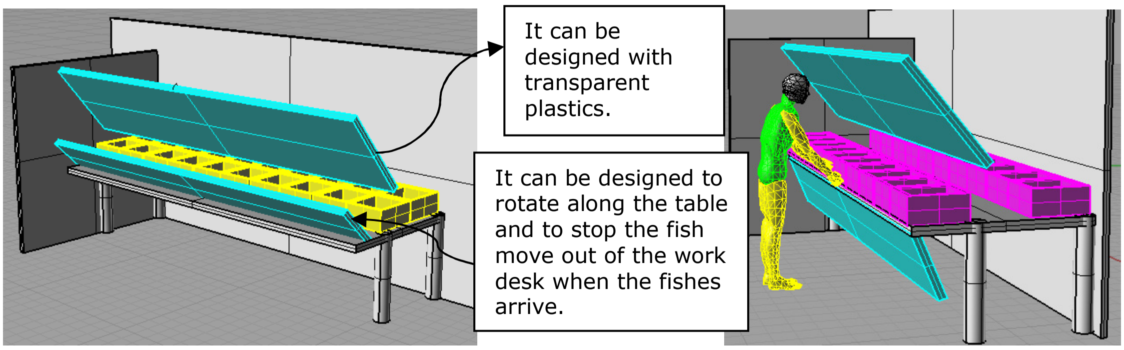


Figure 6 The idea of avoiding pick up the fishes from the floor. And the simple structure will help to locate the fishes correctly fall inside the boxes

CONCLUSION

In this study, we have found that the workplace on board a fishing vessel presents a typical example of a risky work environment marked by severe occupational hazards. The current onboard workplace needs to be redesigned from an ergonomic and human-centered point of view. A suitable work desk is strongly needed for many onboard tasks if the fishermen are to have good working postures. However, the size of the onboard workplace is limited. Using devices for collecting fish and transporting boxes for stacking is very difficult. Therefore, there is a need for further innovation and redesign of the onboard workplace in order to reduce the hazards involved.

In our study, we have found ergonomic digital human modeling for simulating the workplace and work postures to be a very effective tool for assessing the workplace and preventing occupational hazards on board fishing vessels. We have made several recommendations to the final vessel designer as to how to redesign the workplace in order to reduce hazards in the fishing industry. In regard to computer software, on the other hand, we have found that the interface and feedback display of the ergonomic digital human modeling system has to be improved in the future.

ACKNOWLEDGMENTS

I would like to thank Veronica Rayo for her cooperation in the research and Mrs. Judith Mayers for correcting the English in this paper.

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