Using Ergonomic Digital Human Modeling in Evaluation of Workplace Design and Prevention of Work-Related Musculoskeletal Disorders Aboard Small Fishing Vessels

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Abstract

This article seeks to present methods for preventing work-related musculoskeletal disorders of Spanish fishermen and for redesigning the workplace aboard 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 were 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 aboard vessels was modified on the basis of acceptable simulated work postures to prevent repetitive movements, awkward working postures, and lower back biomechanical stresses. In the fourth step, ergonomic design parameters were provided to vessel designers. © 2011 Wiley Periodicals, Inc.

Keywords: Work-related musculoskeletal disorder (WSMD); Physical risk factors; Vessel ergonomic design; Postures simulation; Work place; Digital human modeling

1. INTRODUCTION

In the past 12 months, 8.6% of workers in the EU experienced work-related health problems: This number corresponds to 20 million persons. Meanwhile, back problems (28%); neck, shoulder, arm, or hand problems (19%); and stress, depression, or anxiety (14%) are most often reported as the most serious health problems (Eurostat, 2009). In this report, 70% of fishermen have been exposed to one or more factors adversely affecting physical health; this number is only slight less than the number of workers in the mining sector (75%). The European Foundation for the Improvement of Living and Working Conditions (2007)presents that almost a third (30.7%) of Spanish workers believe that their workplace design is lacking quality in some way. The most arduous working positions affect farmers, stockbreeders, fishermen, and sailors in particular; in all of these professions, 15.4% of workers carry out their work with a bent back.

In Spain, it has been concluded (Ruiz & Ledesma, 2008) that work-related musculoskeletal disorders (WMSDs) (in particular, low back pain [LBP]) are some of the most important problems of the fisherman population. In fact, the official data from the Spanish Labour Ministry about accidents in 2007 show that WMSDs represent the main cause of accidents in fishermen (more than 25% of the registered cases).

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The term "musculoskeletal disorder" (MSD) is used collectively for symptoms and disease of the muscles, tendons, and/or joints. WMSDs and injuries occur when there is a mismatch between the physical requirements and the physical capacity of the human body (Taelman, Adriaensen, Spaepen, Langereis, Gourmelon, & Van Huffel, 2006). Consequently, WMSDs and injuries are caused by a combination of risk factors such as repetitive motion, excessive physical exertion, and bad and/or awkward working postures. Posture as a source of musculoskeletal illnesses such as low back diseases have attracted the most attention, however. Musculoskeletal problems related to repetitive work are also connected to posture.

There are a few studies related to WMSDs in some countries. Swedish studies on fishermen have shown that symptoms from the musculoskeletal system are common and that they follow a logical pattern according to the fishing and type of working tasks on board. During the 12 months before the study, 74% of the fishermen had experienced symptoms of the musculoskeletal system (Torner, Blide, Eriksson, Kadefors, Karlsson, & Petersen, 1988). The authors found that the largest number of fishermen considered the motion of the vessel to be a major strain, not only on the musculoskeletal system, but on the individual as a whole. In their research of work-related injury in New Zealand commercial fishermen, Norrish and Cryer (1990) found that 139 of the 307 cases were diagnosed as strains or sprains. Back strain (87 cases) represented almost two thirds of these and 28% of the total injuries. This finding agrees with the finding that more than one third of the injuries (121 cases) were recorded as having occurred during lifting, lowering, loading, or unloading and that boxes (probably containing fish in many cases) were specified in 28 of these cases. The worker's compensation for back strain injuries was 36% of the total cost, and indicates the importance of this injury group. Strains of the knees, shoulders, and forearms were also common.

To quantify biomechanical stresses on the lumbar spine during work activities of commercial crab fishermen, and thus determine work task priorities for ergonomic intervention, the continuous assessment of back stress methodology was used to develop distributions describing the amount of time that each of the members on a two- or three-man crabbing crew spend at various levels of low back stress (Mirka, Shin, Kucera, & Loomis, 2005). An observational work-sampling technique—Posture, Activity, Tools, and Handling—was used to describe the prevalence of awkward postures and other physical risk factors for shoulder symptoms among a purposive sample of 11 small-scale commercial crab pot fishing crews (Kucera & Lipscomb, 2010).

LBP is a generic term for various low back diseases. It has many causes, and posture is one possible causal element (Kuorinka, 2010, website of International Labour organization). Epidemiological studies have shown that physically heavy work is conducive to LBP and that postures are one element in this process. There are several possible mechanisms that explain why certain postures may cause LBP. Forward bending postures increase the load on the spine and ligaments, which are especially vulnerable to loads in a twisted posture. External loads, especially dynamic ones, such as those imposed by jerks and slipping, may increase the loads on the back by a large factor. From a safety and health standpoint, it is important to identify bad postures and other postural elements as part of the safety and health analysis of work in general.

This study was done in Catalunya, Spain, where there are 1349 fishing boats, and 57% are small fishing vessels. The main goal of our research was to identify and assess the risk factors of WMSDs in fishing tasks of Spanish fishermen and to evaluate the workplace design aboard in-shore small fishing vessels.

There are many challenges to identifying and assessing the risk factors on board fishing vessels. In our case, there are three main research problems that have to be solved: 1) ergonomics analyses related to workplace layout design; 2) studies of fishermen's working postures while catching, handling, lifting, and storing fish; and 3) workplace redesign and construction to prevent WMSDs on board fishing vessels.

Integration of the human factor and ergonomics in the design and construction of fishing vessels has been studied by many research groups (Chauvin, Le Bouar, & Renault, 2008; Orosa & Oliveira, 2010). For instance, personnel movement simulation has been integrated into preliminary ship designing for testing vessel layout suitability (Andrews, Casarosa, Pawling, Galea, Deere, & Lawrence, 2007). The project led to improved ship design, provided a major savings 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. 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 (Keyserling, Armstrong, & Punnett, 1991). Additionally, a comparison between occupational injuries in the French sea fishing industry in the 1980s and those of today was carried out (Chauvin & Le Bouar, 2007). 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 WMSDs (Chang & Wang, 2007). 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 1) the ability to perform ergonomic assessments in the early design process and 2) 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 (Lamkull, Hanson, & Ortengren, 2009). The results of that study show that ergonomic digital human modeling (EDHM) tools are useful for providing designs of standing and unconstrained working postures. However, Using EDHM tools to simulate work processes and postures for purposes of risk prevention has not been adequately done.

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

2. METHODS

Manual handling involves the movement of heavy loads by hand or bodily force, and should be avoided when possible. Work-related upper limb disorders arise mainly from performing repetitive actions. If avoidance 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; and 3) training workers in good practices such as proper handling techniques (Agilent Technologies, Inc., 2007).

To improve on board workplace design, one must first simulate the work process and the work postures of the fishermen. Figure 1 depicts the work flowchart for the ergonomic redesign of the workplace aboard fishing vessels.

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, three-dimensional (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 centered designs. Moreover, ManneQuin PRO is conveniently equipped with the Revised National Institute of Occupational Safety and Health 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.

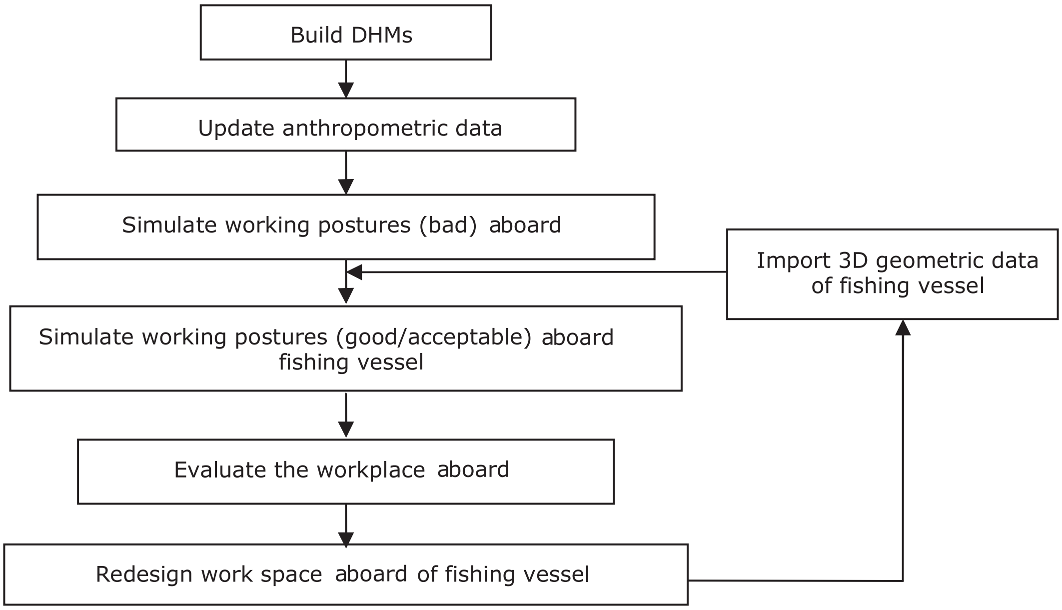


Figure 1 Work flowchart of ergonomic redesign of work areas aboard fishing vessel.

Figure 2 Purse seining fishing method.

2.1. Risk Factor Identification and Assessment of Working Aboard Small Shipping Vessels

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 (Fishing on line). Figure 2 describes the steps used in purse seine fishing.

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

1. Pulling the net through the water to make a type of wall;
2. Gathering up the net;
3. With scoop nets, placing fish into boxes;
4. Arranging fish into empty boxes until boxes are full;
5. Placing ice on fish;
6. Collecting fish from the floor and placing them into boxes;
7. Carrying boxes to pallet and stacking; and
8. Lowering boxes from ship at port.

After getting permission, we used a video camera and a digital camera to record the working tasks aboard one fishing vessel. Other data related to work organization and time shifting was also collected during three days of observation on board. The fishing boat leaves at 9 o'clock in the evening and comes back to download fish at approximately 6 o'clock the morning of the next day. The first step of our research was to identify and assess risk factors in working aboard small fishing

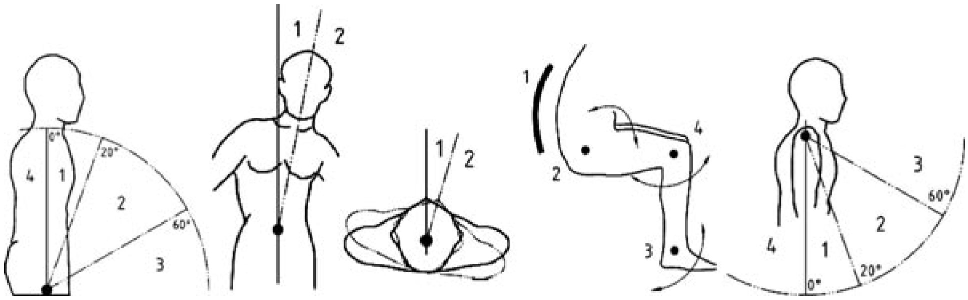


Figure 3 Typical hazardous postures on board fishing vessels. Left to right: Trunk bending forward/backward; sideways; twisting; low back and lower extremities; and upper arm posture - EN 1005-4:2002(E).

Figure 4 Examples of occupational risks in the work areas and tasks aboard small fishing vessels.

vessels, based on videos and images collected on board. The hazard parameters and the cause of the parameters of all the working postures (including postures of catching, pushing, lifting, and pulling) were identified and assessed.

Figure 3 displays the typical hazard postures aboard 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 shows some examples found aboard small fishing vessels of work areas 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 to pick up the remaining fish and put

TABLE 1. Identification Risks from Working Postures

Task a: Arrange the Fish Inside the Boxes		Task b: Pick the Fish up 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° with high frequency and over 60° is NOT ACCEPTABLE	Flexion of the torso between 20° and 60° with high frequency and over 60° is NOT ACCEPTABLE	FORBIDDEN	FORBIDDEN	Flexion of the torso between 20° and 60° with high frequency is NOT ACCEPTABLE	Flexion of the torso between 20° and 60° with 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

them in the boxes. This squatting posture is completely forbidden according to International Organization for Standardization (ISO) standards. Figure 4c presents a fisherman manually carrying and stacking boxes one on top of the other. Table 1 depicts the risk factors for each of these three tasks.

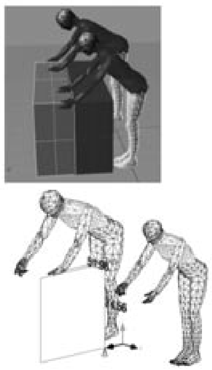
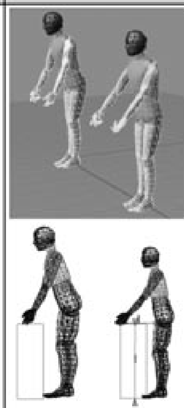
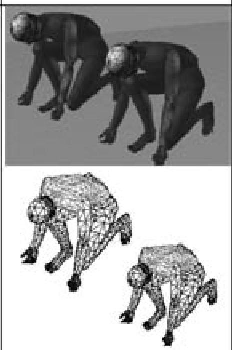
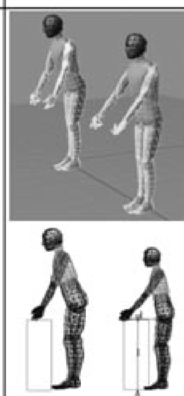
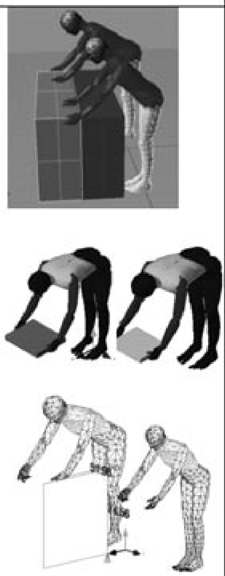
2.2. Simulation of Bad or Awkward and Acceptable Working Postures

After identifying risk factors, the next step was 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 (Sanders & McCormick, 1992). 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. According to statistics from December 2007, there are 50,309 fishermen in Spain (Carmona, 2003). Among these fishermen, 4% are women. 5% and 95% percentiles of Spanish fishermen (men) were selected. The anthropometric data of the ergonomics software (ManneQuin Pro) had been semi-updated. In other words, only weight and height in the original anthropometry data were updated to the ones of Spanish fishermen. Other anthropometry data, such as sitting height, should breath, and so forth, were applied based on the French population.

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, to better describe actual conditions for workers of different sizes working in the same workplace.

TABLE 2. Findings from Analysis Using EDHM in Simulating Three Task on Board Small Fishing Vessels

Task	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 ° 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 ° and 60 ° at high frequency. Lateral tilt of trunk> 10 ° at high frequency. Torque of trunk> 10 ° 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)	

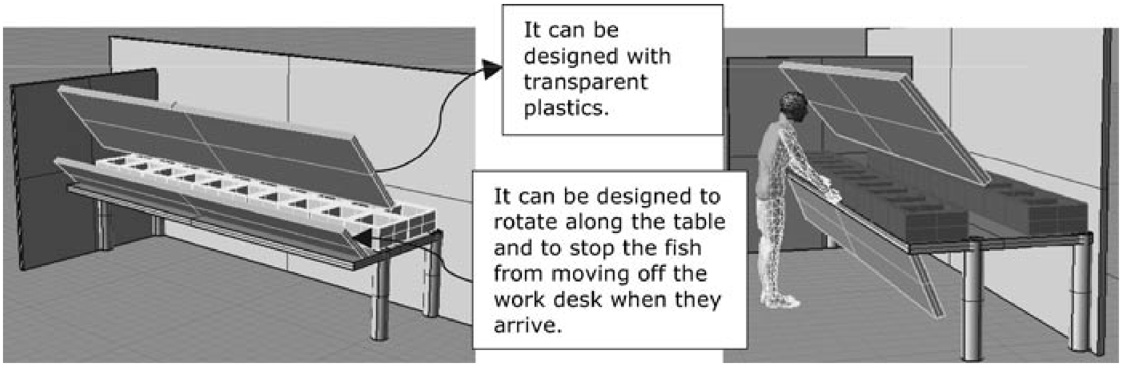


Figure 5 An idea to avoid picking up fish from the floor. The simple structure will help to correctly place the fishin the boxes.

2.3. Inputting 3D Geometric Data of Designed Fishing Vessel into ManneQuin Pro

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

3. RESULTS

By using an EDHM system and simulating all on board work postures, we found multiple risk factors aboard fishing vessels. In contrast, we also found solutions for redesigning the work areas on board to prevent occupational hazards in fish collection, processing, transportation, and storage.

3.1. Redesigning Work Areas Aboard Shipping Vessels Based on Acceptable Working Postures

In this article we present our research findings in the tables. Table 2 presents the findings of our analysis of three tasks aboard small fishing vessels. Task A is to arrange the fish in boxes until the boxes are full. Task B is to collect the fish from the floor and put them into the boxes, Task C is to transport and stack the 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. In other words, the upper body is in red, which indicates that it is in a posture with risk of developing an MSD. 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.

3.2. Recommendation for Ergonomics Workplace Design

In our simulation of the workplace aboard fishing vessels, we found that there was inadequate foot clearance in the current workplace when fish boxes were being stacked. Foot clearance is an important design parameter if fishermen are to maintain good working postures; therefore, we made some recommendations in connection with the design of the workplace aboard fishing vessels. To avoid picking up fish from the floor and working on one's knees, we have designed a fish collecting table, which is presented in Figure 5. Figure 5 shows how the workplace can be redesigned 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.

4. CONCLUSION

In this study, we have found that the work areas aboard a fishing vessel present typical examples of a work environments that pose risks to workers regarding the development of WMSDs. The risk factors of MSD have to be controlled at the source, and the risks have to be minimized by such means as the design of safe work systems. Consequently, the current on board workplace needs to be redesigned from an ergonomic and human-centered point of view. A suitable work desk is needed for many on board tasks if the fishermen are to have good working postures. The size of the on board workplace is limited, however. Using devices for collecting fish and transporting boxes for stacking is difficult. Therefore, there is a need for further innovation and redesign of the on board workplace to reduce the risk factors involved.

In contrast, we also have found EDHM for simulating the workplace and work postures to be an effective tool for assessing the workplace and preventing WMSDs aboard fishing vessels. We have made several recommendations to the final vessel designer as to how to redesign the workplace to reduce hazards and risk factors involving manual handling operations in the Spanish fishing industry. With regard to computer software, additionally, we have found that the interface and feedback display of the EDHM system has to be improved in the future.

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