Assessment of biomechanical risk at work: practical approaches and tools

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The paper illustrates some methods and tools supporting work related risk assessment with reference to ergonomics and biomechanics, in particular. These aspects will also be described through the analysis of two case studies in order to highlight the main characteristics and problems found during the application phase. Furthermore, using modelling and simulation software, the utility and reliability of such tools in support of the work related risk assessment will also be evaluated.

Keywords: work related, risk assessment, manual lifting, repetitive handling, human physical performance

1 INTRODUCTION

Risk assessment aims at adequately protecting workers' health and safety. For this reason, the available tools and methods should facilitate assessments that are as rigorous and reliable as possible. This contrasts with the necessity, related to practical field applications, of having flexible tools that do not require the employment of laboratory equipment and can also be used by non-expert evaluators. In the light of these considerations, the authors find it necessary to verify not only the availability of methods and tools that consider the most up-to-date, consensual knowledge, but also that such tools are the result of an ideal compromise between the contrasting illustrated needs. The article will therefore analyse and assess the effective applicability, in particular job contexts, of the methods of assessment. It will also verify the possibility of using simulation software in support of the activities of biomechanical risk assessment and will attempt to determine what sort of support and assistance such software can provide.

The article has the following structure:

- a brief description of some risk assessment methods suggested by technical standards;
- a description of two case studies in which these methods were applied;
- the presentation of assessments of the same risks using simulation software applied to one of the two case studies;
- a comparative analysis of the results obtained.

2 MATERIALS AND METHODS

2.1 Risk assessment: legislative requirements and practical procedures

Council Directive 89/391/EEC introducing measures to encourage improvements in health and safety at work has made risk assessment and documentation mandatory. At a general level, risk assessment must be specific to each worker, and must be a continued sequential process consisting of the following main stages:

- identification of each hazard and the related risk factors in the workplace;
- identification of the workers exposed to the risk factors identified;
- determination and assessment of the exposure level to the risks identified;
- integration of the assessment of exposure with subjective or non-occupational aspects;
- identification and planning of preventive and protective actions;

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- periodic review of the assessments and improvements identified and their application.

National laws and international as well as European technical standards provide concepts, methods and operating tools that serve to study and understand the role of risk factors in determining the risk level. They can therefore be a useful support for risk assessment, especially in the exposure analysis stage.

These tools serve to assess the exposure level to biomechanical risk factors, such as low back pain caused by manual handling, and upper limb pathologies caused by repetitive movements at high frequency.

In particular for the purposes of this article, the reference technical standard at the European level is EN 1005 "Safety of machinery - Human physical performance". It contains five parts dealing with: terms and definitions, manual handling, recommended force limits, working postures and movements, and repetitive handling at high frequency.

At the international level there are two standards: ISO 11226: 2000 "Ergonomics - Evaluation of static working postures" and ISO 11228 "Ergonomics - Manual handling", which contains three parts dealing with lifting and carrying, pushing and pulling, and handling of low loads at high frequency.

2.2 Manual lifting: determination and evaluation of Risk Index

The NIOSH (National Institute for Occupational Safety and Health) method [1], proposed in EN 1005-2: 2003 and ISO 11228-1: 2003, applies to risk assessment concerning lifting, lowering and carrying and provides the evaluation of the exposure level (Risk Index) by means of the quantification of some relevant risk factors. Calculation of the Risk Index is based on the characterization of the lifting tasks carried out by the operator and on the analysis of the different factors. For each task, the Risk Index is calculated using the following equation:

$$\text{Risk Index} = \frac{\text{actual mass}}{R_{ML}}$$

where R_{ML} is the Recommended Mass Limit:

$$R_{ML} = M_{ref} \times V_M \times D_M \times H_M \times A_M \times C_M \times F_M$$

The different terms have the following meanings:

- M_{ref} is the reference mass (that takes into consideration the intended user population);
- V_M, D_M, H_M, A_M, C_M, F_M are multipliers (between 0 and 1) for the risk factors "vertical location" (V_M), "vertical displacement" (D_M), "horizontal location" (H_M), "angle of asymmetry" (A_M), "coupling" (C_M) and "frequency" (F_M).

The values of the coefficients can be obtained through equations or tables. From the observation of the tasks carried out and analysis of the information regarding the work organization, as well as on-site measurement of workplace areas and work rates, it is possible to quantify the corrective factors and the recommended maximum weight.

The Risk Index can be used to estimate the relative magnitude of physical stress for a job. The higher the Risk Index figure, the smaller the fraction of workers capable of safely sustaining that level of activity. The index also supports assessment through its comparison with the risk ranges proposed by the NIOSH method.

2.3 Repetitive movements at high frequency: determination and evaluation of OCRA Index

The OCRA (OCcupational Repetitive Actions) method [2], proposed in EN 1005-5: 2007 and ISO 11228-3: 2007, presents a risk assessment approach (OCRA Index) intended for reduction of the exposure level to repeated movements of upper limbs. OCRA method considers the impact of most significant risk factors simultaneously and in an integrated way, in order to facilitate the preventive or corrective actions on critical factors.

For a given task, the OCRA Index is calculated by the following equation:

$$\text{OCRA Index} = \frac{\text{ATA}}{\text{RTA}}$$

where ATA are the Actual Technical Actions (obtained analysing videotapes of the specific work-tasks) and RTA are the Reference Technical Actions needed in the shift:

$$RTA = CF \times Fo_M \times Po_M \times Ad_M \times Re_M \times D \times Rc_M \times Du_M$$

The different terms have the following meanings:

- CF is the constant of frequency (CF = 30 technical actions per minute);
- Fo_M, Po_M, Ad_M, Re_M are multipliers (between 0 and 1) for the risk factors “force” (Fo_M), “postures” (Po_M), “additional” (Ad_M) and “repetitiveness” (Re_M) in the considered task;
- D is the net duration of repetitive task, in minutes;
- Rc_M is the multiplier for the risk factor “lack of recovery period” (between 0 and 1);
- Du_M is the multiplier according to the overall duration of repetitive tasks during the shift (also higher than 1).

Multiplier factors value can be obtained by tables. The OCRA index supplies values that increase when the level of risk exposure is higher.

3 CASE STUDIES AND RESULTS

This section presents and analyses two real cases of exposure assessment through the use of the tools previously described, as well as the use of software (JACK[1]) supporting the integrated ergonomic assessment in the first of the two cases. The applications have been carried out by the authors in two Italian companies.

Among the different simulation tools available, the JACK software was chosen as it is endowed with criteria of analysis that focus specifically on the assessment of anthropometric and biomechanical risks and is thus particularly suited to the types of activities that were being studied.

It should be noted that the JACK software was used for the following specific purposes:

- to ascertain the concrete applicability of the software to operating contexts characterized by rather high complexity;
- to perform a qualitative and quantitative comparison of the results obtained applying traditional methods with those provided by modelling and simulation software.

3.1 Manual lifting: the case of glass products inspection

The analysed activity consists of an operation of visual and tactile inspection of hot-formed glass products in a mid-size industrial plant. The work rate is partially set by the machinery, the pace of which determines the frequency of product handling. The operator works standing up and takes the molded products off a conveyor belt that extracts them in parallel rows from the annealing kiln; the task consists of verifying the absence of flaws by lifting the product and inspecting it against a special light. The operator accepts only non-faulty products, which are collected in groups of several units, while the defective ones are rejected and placed on another conveyor belt that recycles the glass. When the approved products reach the established number, the group has to be lifted and placed inside a cardboard carton located on the right-hand side of the operator. The carton is then closed, lifted and placed on a pallet situated behind the workstation (Figure 2). The activity is repeated throughout the shift, which is 7.5 hours for male operators, but no more than two hours for female operators. Breaks can be taken only by agreement with a “spare” operator who substitutes for the operator as it is not possible to interrupt the flow of products leaving the kiln. The workplace areas are partially linked to the characteristics of the kiln and influence many of the parameters considered when calculating the Risk Index.

Figure 1 illustrates the operations included in the cycle, the number of products and cartons lifted and the cycle time.

[1] www.plm.automation.siemens.com

BRIEF DESCRIPTION OF THE TASK, THE CYCLE AND COUNT OF MANUAL LIFTS

TASK : Inspection and packing

	DESCRIPTION	DX	SX
1	Macro-operation: handling empty carton	1	1
2	Macro-operation: inspection and grouping glass products	8,06	8,06
3	Macro-operation: handling gruop and full carton	1	1
	TOTAL PRODUCTS LIFTED	8,06	8,06
	TOTAL CARTONS LIFTED	1	1

	ITEMS	CARTONS
CYCLE TIME	64,5	64,5
LIFTS WITH RIGHT LIMB	8,06	1
LIFTS WITH LEFT LIMB	8,06	1

FREQUENCY OF LIFTS PER MINUTE

	DX	SX
ITEMS	7,5	7,5
CARTONS	0,93	0,93

Figure 1 - Manual lifting: operations and cycle time

The parameters are associated with the risk factors described in paragraph 2.2 using the relations set out by the NIOSH method. It is then possible to quantify the exposure level and calculate the Risk Index.

According to the analysis performed, and considering the task duration, handling products heavier than 5 kg is critical (Risk Index = 1.23). Furthermore, handling cartons heavier than 15 kg is near the acceptability threshold, regardless of the handling frequency, and could become critical if carried out improperly. For the female operators, who have a shorter task duration, the heaviest product remains critical (Risk Index = 1.04).

Figure 2 - Glass inspection case: lifting carton

The results of the application of the NIOSH method were integrated with other considerations of a technical and productive nature; this led to the introduction of corrective and ameliorative measures. For example the work tables were set at a height at which the operator's hands, during the execution of the activity, were about 75 cm from the ground. This improved the conditions of performance of the task both in terms of posture and of the exertion required to perform the activity.

On an organizational level, a training program was developed to teach the operators how to perform the activity avoiding overexertion and/or unnecessary movements. Furthermore, an operating procedure was developed to define correct performance of the visual inspection stage so that operators could avoid over-lifting the object unless absolutely necessary.

3.2 Repetitive movements at high frequency: the case of manual deburring of manifolds

This section describes the analysis made for the purpose of characterization of the exposure to repeated efforts of the upper limbs on manual manifold deburring workstations in an Italian company operating at the international level.

The activities are defined by specific instructions which describe the operating cycle to be carried out and outline all the required technical actions. Operations actually performed may be subject to modifications, on the basis of the quantity and type of the burrs found on the manifolds (Figure 3). In order to assess the risk from movements involving repetitive strain on the upper limbs, it is necessary to identify and discriminate between the tasks subject to analysis; for this purpose, the literature indicates as repetitive tasks those which contemplate the consecutive performance, for at least one hour a day, of similar processing cycles of brief duration (a few minutes) that require, for their performance, actions of the upper limbs.

Considering the characteristics of the tasks analysed, the assessment was performed taking as a single repetitive task that of picking up one or more products, removal of the burrs with files or reamers, brushing the holes and performing all the other activities required by the work procedure for the items being produced, up to their placement inside the metal basket that is then sent on for washing.

For the purpose of this assessment, the activities of visual inspection, recovery of the pallet containing the manifolds for processing, finding, picking up and consulting the instructions sheets for the deburring operations were not considered repetitive tasks.

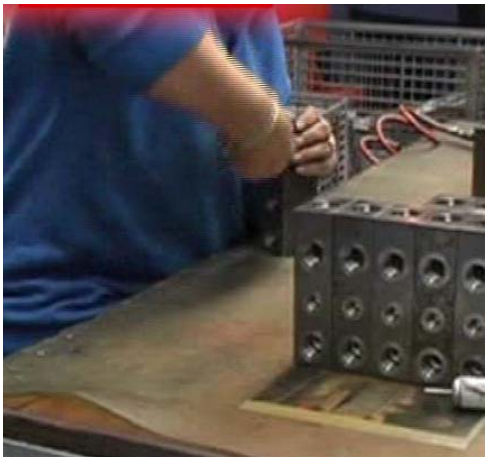

Figure 3 - Manual deburring activity

Work activities take place over a period of eight hours. There is a lunch break, two 8-10 minute breaks (one in the morning and one in the afternoon) and some physiological breaks. The work rate is not imposed by the machinery nor by the operating cycles, but rather is self paced by the operators.

By examining videotapes taken of the workers, it was possible to determine the number of technical actions performed during processing, evaluating separately tasks involving the two upper limbs and it was possible to establish the duration of each activity and thus determine the effective time cycle. In this connection it should be noted that the situation examined differs from the usual spheres of application of the OCRA method (assembly lines with binding pace) in which the processing time is largely defined by the production line.

Subsequently, on the basis of the duration of the shift, the breaks and the non-repetitive activities, it was possible to calculate the number of cycles performed during the shift and the number of technical actions performed with the right and left upper limb.

Figure 4 illustrates the operations included in the cycle, the number of technical actions and the cycle time.

BRIEF DESCRIPTION OF THE TASK, THE CYCLE AND IDENTIFICATION OF THE TECHNICAL ACTIONS

TASK : Deburring of manifolds

	DESCRIPTION	DX	SX
1	Macro-operation: loading manifolds onto the bench and use of scrapers	294	260
2	Macro-operation: use of drills and files	186	141
3	Macro-operation: use of brushes and offloading of manifolds into basket	489	180
4	Macro-operation: other possible actions		
	TOTAL	969	581

	TASK
CYCLE TIME	1563
ACTIONS PER CYCLE OF THE RIGHT LIMB	969
ACTIONS PER CYCLE OF THE LEFT LIMB	581

FREQUENCY OF ACTIONS PER MINUTE

	DX	SX
TASK	37,2	22,3

Figure 4 - Repetitive movements: operations and cycle time

The RTA was calculated on the actual conditions of the activities being carried out and was based on the following considerations:

- force: examined on the basis of a subjective judgment scale, made also using the indications supplied by the female operators during the interviews (for a more precise analysis an EMG can be required, as pointed out in [3]);
- posture and movements: the most critical situation is for the right upper limb and is linked to the removal of the burrs requiring shoulder abduction (see also [4]);
- additional factors: vibrations transmitted to the hand-arm system by the pneumatic devices and slipperiness of the manifolds that are sometimes lightly greased;
- recovery time: on the basis of the information gathered, it is hypothesized that in each shift there are no more than 2 hours without an adequate rest.

In a specific workplace, during the deburring of the most complex product, the OCRA Index was 2.61 for the right limb and 1.40 for the left limb.

These values identify a risk level that is presumed to be negligible for the left limb and very low for the right limb. The situation is deemed acceptable for the left limb. However, the right limb needs additional examination because of other elements, including personal aspects, that are not adequately considered by the OCRA method. Some modifications to the workstation and procedure have been introduced to improve the workplace and the tasks evaluated.

3.3 Integrated ergonomic assessment through the use of the JACK software

The JACK software was developed by the Computer Graphics Laboratory of the University of Pennsylvania to complete a set of tools designed for modelling and simulation, and to consolidate the use of certain assessment techniques capable of supporting the enterprises in the analysis and improvement of the ergonomic aspects of product design and organization of the workplace, from the anthropometrical and biomechanical viewpoint. The aim of the software is to furnish the analyst with tools of support in the assessment of the work system and determine whether the tasks assigned to the operator can be performed safely and without the risk of excessive physical fatigue, discomfort, injury or the development of professional diseases.

Close observation of the above-mentioned work operations indicates a potential usefulness of the JACK software in facilitating traditional ergonomic assessment of the workplace and of the specific tasks. In the situations analysed, the main risk factors are predominantly of the anthropometric and biomechanical type [5] and the JACK software has been specifically developed for this type of application. Modelling requires a reconstruction of the work environment, the operator and the tasks in order to define and reproduce the work situation, as shown in Figure 5. The combined use of the tools available in JACK supports an integrated and multifactorial analysis of the work system making it possible, for example, to identify the optimum arrangement of devices and equipment. Three examples are shown in Figure 6: the operator’s reachable areas, the cone of vision of the operator and the performance of the activity as seen through the eyes of the operator/mannequin.

Figure 7 illustrates some of the tools used for posture analysis and characterization of the exertion required. The analyses were conducted using both the software and the most acknowledged criteria and methods available in literature. Even if a precise comparison of the numerical results is not possible, the global evaluations appear to be consistent on a general level and regarding the identification of situations or activities as potential sources of risk.

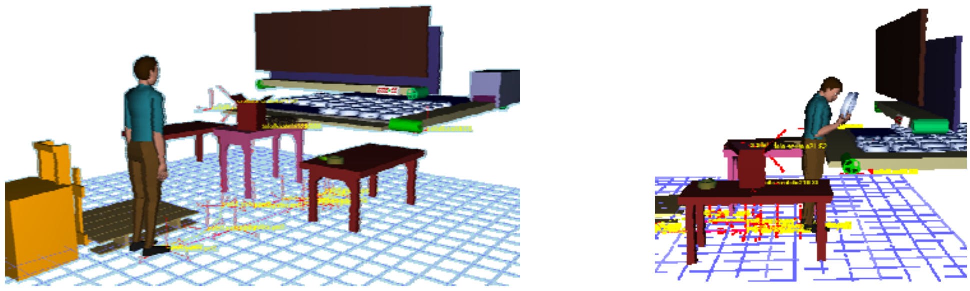

Figure 5 - Reconstruction of the work environment using the JACK software

Figure 6 - Visualization of the reaching area and of the cone of vision

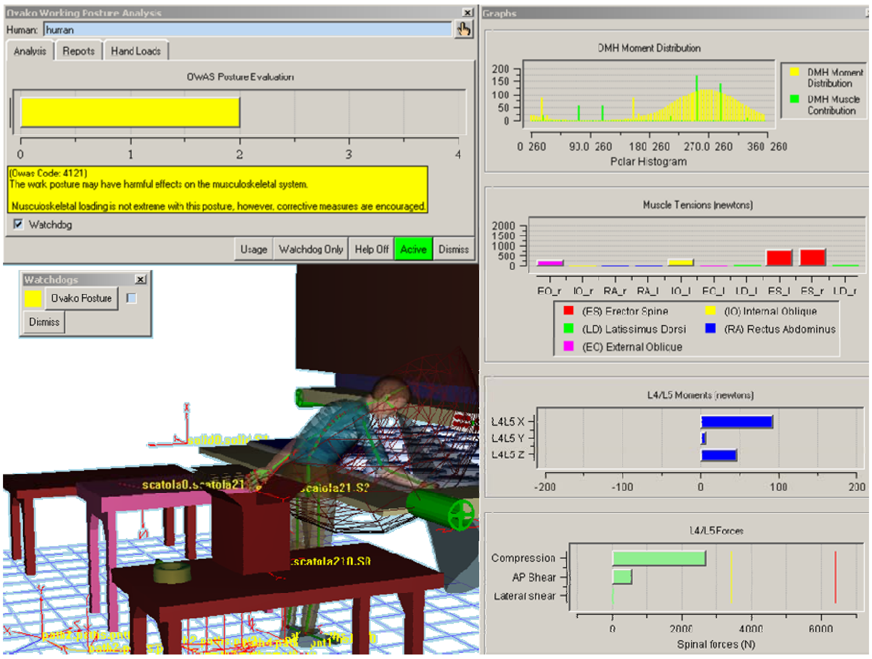

Figure 7 - Example of available tools for the analysis of a work task

4 CONCLUSIONS

The cases described in the above paragraphs show the application of the operating methods for the determination of the biomechanical work related risk exposure level proposed by the technical standards in unconventional situations. Such situations are, in fact, characterized by a high variability of the factors considered, and do not have direct reference to the more traditional and simpler cases, such as an assembly line, for which such criteria were originally designed.

The problems encountered in these applications are related both to the concrete use of the methods proposed (in particular the OCRA method), and to the need to adapt the models used to specific work situations. For example, the deburring activity was characterized by high variability of the exposure because of the operators' use of different personal techniques for deburring and because of the number of items, approximately 2,000, different in weight, number of holes, material, etc.

During the performance of these kinds of assessments it is therefore necessary to:

- identify the method of screening to facilitate recognition of the most critical situations that must be subjected to a more in-depth evaluation;
- elaborate operating methods that group situations or contexts seemingly different, but comparable in terms of risk factor exposure;
- evaluate possible changes of the working conditions and predict their effects on the assessment.

In the case of the glass products, although the work situation appeared easier to examine, the authors found it difficult to identify and introduce effective corrective measures because of the need to compensate for the contrasting consequence that they could have on different risk factors.

In these situations, the use of simulation software can not replace the role of the analyst, but it could support risk assessment since it makes it possible to understand the effects of possible changes.

The employment of this support must be seen as an aid and integration of traditional assessment. Furthermore, imperfect knowledge of the models and reference methods on which such softwares are based could have negative effects on use of the results supplied, as well as on the consequent identification of corrective measures.

In conclusion, the authors can observe how the tools currently available for biomechanical risk assessment have reached a very good level of development. Such tools can support a multifactorial analysis of the problem, but they still require important adjustments to suit the particular characteristics of the situation analysed.

Moreover, the use of modelling software may facilitate evaluation of the effects of introducing simplifications in the modelling of a work system, in support of the identification of the less significant aspects that, for the sake of convenience, may be overlooked.

With a view to quantitative analysis, it was possible to observe a general agreement between the evaluations obtained with the application of the methods set forth by the technical standards and using the JACK software; however it was not possible to make a precise control of the results obtained due to the different assessments tools implemented in the software. For example, with reference to the assessment of risks due to manual handling of the products examined in the first case, though the assessment criteria applied were slightly different, the risk range was the same.

On the basis of these practical experiences, the authors must add to the foregoing remarks that the methods proposed in the technical standards present some non-negligible limitations. These limitations include, for example, with reference to application of the NIOSH method, inadequate consideration of the anthropometric differences among workers performing the same activity. With reference to the OCRA method it must also be observed that there is some difficulty in adapting the method to non-standard tasks that do not closely resemble the processing methods typical of assembly lines for which the OCRA method was developed.

Overcoming these limits could be an interesting goal for future development and research, as long as complexity of the methods is not increased and their applicability in the field is ensured.

5 REFERENCES

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