PROCESS ERGONOMICS OF MOTOR VEHICLES

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1. INTRODUCTION

Sustainability can be defined as “the development that meets the needs of the present without compromising the ability of future generations to meet their own needs”. Therefore, it includes attention to natural resources as well as to human and social resources, in combination with economic sustainability [1,2].

It is often deemed [3] that ergonomics can contribute to developing actions and programmes aimed at combining the human and economic dimension of sustainability and social responsibility by optimizing both system performance and human well-being.

Ergonomics focuses on systems in which humans interact with their environment. The environment is complex and consists of the physical environment, the organizational environment and the social environment.

Ergonomics takes a system (holistic) approach, that is a broad perspective of the human within the environment. A system approach is fundamental, and the object of analysis, assessment and design, simple as it may be, must always be represented with due consideration of all foreseeable inter-correlations. In real work systems, conceptually different issues do overlap and interact, sometimes in complex ways, and investigations that are restricted to one core science and one level of analysis are almost always unsatisfactory [3].

Ergonomics also typically takes a hierarchical approach, where environmental design to fit the human is seen as a priority, and training people to fit the system is only considered when the former is not possible. With a better fit environment, humans are better able to contribute to performance. End target of ergonomics is not only that of preventing accidents and illness, but mainly that of promoting good health as psycho-physical well-being.

In Europe, protection of workers’ good health is regarded as a public responsibility. European directives on safety and health at work have their legal foundation in Article 153 of the Treaty on the Functioning of the European Union, which gives EU the authority to adopt directives in this field. A wide variety of directives, setting out minimum health and safety requirements for the protection of workers, have since been adopted. Member States are free to adopt stricter rules for the protection of workers when transposing European directives into national law, and so legislative requirements in the field of safety and health at work may vary across Member States.

Generally, a directive fixes the agreed objectives to be pursued by the European Member States, but leaves freedom of choice in how to achieve them. These directives are supplemented by a series of European EN standards, which fill out the details and enable implementation.

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The International Organization of Standardization (ISO) has published international standards which deal with ergonomic requirements for workstations, methods of risk assessment and other aspects related to muskolo-skeletal disorders (MSDs).

Basic requirements of physical ergonomics are also contained in a chapter of Machinery Directive (98/37/EU). When designing manufacturing systems and machines, ergonomic principles have to applied to improve safety and efficiency for workers and to enhance the working conditions. A good ergonomic design positively affects manufacturing systems and worker reliability. Whenever a machinery and workplace are being designed or re-designed, designers have to take into account the ergonomic basic requirements reported in CEN Standards to evaluate and minimize all related risks.

2. METHODS FOR RISK ASSESSMENT

According to Italian and international legislation, industries are required to perform a risk assessment of the workplace and create a document with evidence of it. All potential risks present at the workplace must be taken into account, including the ergonomics risk. Each workstation is to be analysed with the aim of improving workers' working quality life and allowing for a proper allocation worker-workstation.

For Italian industries, the ergonomics mapping of workstations is based on the Legislative Decree 81/2008, with reference to ISO 11228 standards and EN 1005 standards. Standards suggest a step approach to hazard identification and subsequent risk assessment and evaluation. Acceptability of risks is to be ensured in time through monitoring and reviewing, else the workplace needs to be redesign and re-evaluated.

Main hazards for musculoskeletal injuries in the workplace can be tackled in: (awkward) posture, high and prolonged levels of exerted force, repetition rate and fatigue. Their external counterparts, related to the task, are therefore accountable to workplace layout, loads to be handled, cycle time and work organization (shifts and rest periods). If hazards are present, the level of risk needs to be assessed. A step approach to risk assessment and evaluation is usually advisable. First level methods are risk assessment methods that utilize checklists. They are often called ergonomic screening tools as they allow for a rapid risk estimation. If the risk estimation signals that some risks may be present, a more detailed risk assessment is recommended. Second level methods are risk assessment methods that allow a detailed analysis through computation of indexes. Second level methods are generally utilized after the pre-screening phase.

Complying with the Machinery Directive (98/37/EU), a street light indication is usually given as a result of the risk assessment analysis. Green means that the task entails negligible risks for muskolo-skeletal problems and should be manageable for all healthy employees. Yellow means that some risk may be present and that action should be planned in terms of risk monitoring (medical screening and surveillance) and/or implementation of solutions. Finally, red means that the task implies a high risk and improvement actions are required as soon as possible.

Table 1 summarizes main risk assessment methods reported in the standards and usually taken as reference methods for control of ergonomic risks at manual workplaces. A brief overview of the methods is presented in the following subparagraphs. A fourth subparagraph introduces two methods developed by the Ergonomics Institute of Darmstadt University of Technology (Germany) with specific reference to the automotive industry.

Table 1 *Main risk assessment methods reported in the standards*

TYPE OF WORKING ACTIVITY		**METHOD FOR RISK ASSESSMENT**	**REFERENCE STANDARD**	**TARGET BODY SEGMENT**
Manual Material Handling (loads above 3 kg)	Lifting Tasks	Lifting Index NIOSH	ISO 11228-1 EN 1005-2	back
	Push/Pull & Carry	Tables of Snook & Ciriello	ISO 11228-2	back and shoulders
Handling of low loads at high frequency		OCRA Checklist OCRA Index	prEN 1005-5 ISO 11228-3	upper limb - wrist, elbow and shoulder joints

Lifting tasks: Lifting Index NIOSH

For risk evaluation of lifting tasks, the reference method is the NIOSH lifting equation [4] which is reported in both ISO 11228-1 [5] and EN 1005-2 [6] standards. The NIOSH lifting equation introduces the use of the Lifting Index (LI), a scalar number that provides a relative estimate of the level of physical stress associated with the manual lifting task. The estimate of the level of physical stress is defined by the relationship of the weight to be lifted and the Recommended Weight Limit (RWL).

$$LI = \frac{Actual\,Load\,to\,be\,lifted}{\mathrm{Re}commended\,Weight\,Limit(RWL)}$$

According to NIOSH indication, lifting tasks characterized by LI greater than 1.0 pose an increased risk for lifting-related low back pain. If the magnitude of the LI increases, the level of the risk for the worker performing the job would be increased, and a greater percentage of the workforce is likely to be at risk for developing lifting-related low back pain.

RWL, denominator of the LI ratio, is defined for a specific set of task conditions (Figure 1) as the weight of the load that nearly all healthy workers could deal with over a substantial period of time without an increased risk of developing lifting-related low back pain.

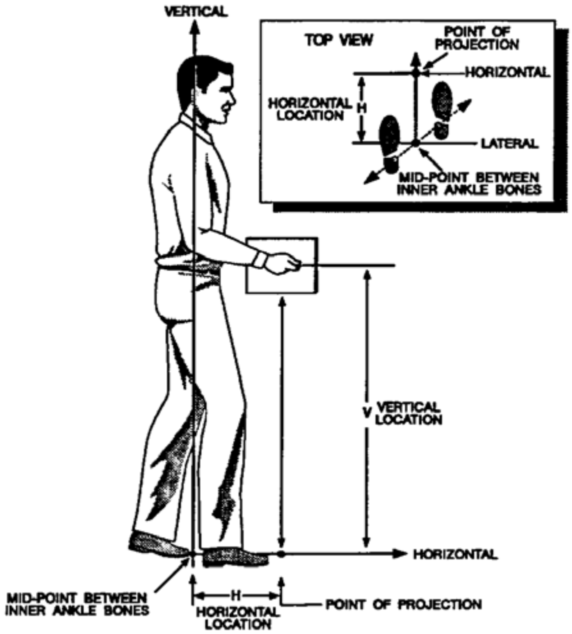


Figure 1 *Task descriptors of NIOSH multipliers [4]*

Calculation of RWL is based on a multiplicative model that provides a weighting for each of six task variables. The weightings are expressed as coefficients that serve to decrease the Load Constant (LC), which represents the maximum recommended load weight to be lifted under ideal conditions (standard lifting location, sagittal plane, occasional lift, good couplings and vertical lift <25 cm):

$$RWL = LC \times HM \times VM \times DM \times AM \times FM \times CM$$

where:

- HM, the horizontal multiplier, depends on the horizontal distance between the worker's ankles and the worker's hands, therefore considering the entity of the bending moment on the worker's spine;
- VM, the vertical multiplier, depends on the vertical distance of the worker's hands from ground, therefore taking into account whether the worker needs to stoop or bend or, on the contrary, raises his/her arms at or above shoulders' level;
- DM, the distance multiplier, depends on the vertical distance between the point of origin and the point of destination of the lift, therefore considering the metabolic effort in the lift;
- AM, the asymmetry multiplier, depends on the extent of trunk rotation required during the lifting task;
- FM, the frequency multiplier, depends on the number of lifts per minute as well as on lifting duration. The latter is specified by distribution of work-time and recovery-time and classified as either short, moderate or long;
- CM, the coupling multiplier, depends on the quality of the gripping offered by the object to be lifted and is classified as either good, fair or poor.

Each multiplier should be computed from the appropriate formula or extracted from a table.

Geometrical parameters are to be evaluated at the origin of the lift, unless significant control of the load is required at destination. Significant condition is defined as a condition requiring precision placement of the load at destination of the lift. This is usually the case when:

– the worker has to re-grasp the load near the destination of the lift;
– the worker has to momentarily hold the object at destination;
– the worker has to carefully position or guide the load at destination.
– For lifting tasks that require significant control at destination, RWL is to computed both at origin and at destination, so to identify the most stressful location of the lift.

With reference to NIOSH indication, LC is set to 23 kg regardless of the operator's gender. The 23 kg weight limit should be protective for 90% of the entire adult healthy population (i.e. 99% of male and 75% of female adult healthy workers). Application in European countries sets different limits of the maximum acceptable load for male and female workers; wishing to be protective for 90% of male and female adult healthy workers, the weight limit is set to 25 kg for adult healthy male workers and to 15-20 kg for adult healthy female workers. Maximum acceptable loads are to be reduced by 5 kg for youth (<18 years old) or older workers (> 45 years old).

For trained healthy adult workers, the weight limits can occasionally be exceeded under particular circumstances (for example maintenance work) but with the guarantee that working conditions remain safe.

Whole-body pushing/pulling and carrying: the Snook & Ciriello Tables

In case the manual material handling involves whole body pushing, pulling and carrying, the commonly employed method for identifying potential hazards and risks refers to the Snook and Ciriello Tables. The Snook & Ciriello psychophysical tables provide limit values of the maximum acceptable initial (static frictional resistance) and sustained (sliding frictional resistance) forces in case of pulling/pushing activities and of maximum weight to be handled in case of carrying.

ISO 11228-2 standard [7] introduces the Risk Index (RI), a scalar number that provides a relative estimate of the level of physical stress associated with a particular pushing-pulling-carrying task.

The estimate of the level of physical stress is defined by the relationship of the effective weight/force value and the recommended limit value obtained from tables. In the case of pushing/pulling activities:

$$RI = \frac{measured\ \ force}{recommended\ \ force}$$

RI is the classified according to a traffic light classification system:

- RI < 0,85 green area, the manual handling is acceptable. No need for intervention.
- 0,85 <RI< 1 yellow area, attention zone. A portion of the working population may be at risk. Workers' education and training. Medical surveillance.
- RI > 1 red area, risk zone. Needs for intervention.

Recommended forces and loads are based on the research carried out by Drs. Snook and Ciriello at the Liberty Mutual Research Institute for Safety [8-11]. Their researches used the psychophysical methodology to analyze and to evaluate lifting, lowering, pushing, pulling and carrying tasks. The results of researches provided important pieces of information about capability and limitations of workers and design of manual material handling tasks to reduce low back disability. The psychophysical methodology includes measurements of oxygen consumption, heart rate and anthropometric characteristics. Subjects were given control of either the weight of force variable; all others task variables, such as frequency, size, distance etc., were controlled by the experimenter.

The tables, published in literature, provide for each type of actions (pushing, pulling and carrying) the maximum acceptable weights and forces depending on the percent protection of male and female adult healthy population (usually taken at 90%). Table values depend on other variables relating to the type of action, such as frequency, height of the handle from floor and covered distance.

Acceptable forces for pushing and pulling are to be compared with the effective measured forces. It is important to note that pulling/pushing forces are not easy to relate to the weight of objects being pushed or pulled because trolley and floor characteristics have to be considered. Indeed pushing and pulling forces have to be measured directly through the use of dynamometers. Moreover, the force required for handling any wheeled device involves several components: starting (initial), stopping, turning and maintaining its motion (i.e., sustained). It is the maximum force generated while completing any of these actions that must be considered in the risk analysis. It is also important to monitor the situation from time to time, to check on the level of maintenance of carts and devices as well as floor conditions.

Whereas lifting, holding and carrying can lead to high compressive loads on the operator’s lumbar spine, the compression forces arising from pushing and pulling are generally much lower. Shear forces on the other hand tend to be higher. To minimise forces on the back, the operator should exert the force with a stable and balanced posture that allow application of his/her own body weight. Load on arms and shoulders is influenced by posture, strongly related to position of the hands. Hands should be at around waist level and should not be too close. Also, the elbows should be kept low.

Handling of low loads at high frequency: the OCRA method

For risk assessment of upper limbs repetitive movements, both ISO 11228-3 [12] and EN 1005-5 [13] refer to the OCRA method. The OCcupational Repetitive Action (OCRA) method was developed in 1996 by two Italian occupational doctors and researchers, Occhipinti and Colombini [14-17]. The method is intended to analyze workers’ exposure to tasks where main upper-limb injury risk factors are present: repetitiveness, force, awkward postures and movements, lack of recovery periods, and others, defined as “additional”. Each identified risk factor is targeted to help identifying possible requirements and preliminary preventive interventions; all factors are then added up to consider overall risk exposure. If job rotation occurs, all repetitive tasks are analyzed and a time-weighted average is calculated for final assessment.

The OCRA method is composed by an index and a checklist. Both methods are mainly observational.

The OCRA index provides a scalar number, representing the ratio between the actual technical actions carried out in the work shift (ATA) and the number of reference technical actions in the shift that can be considered safe under the analyzed working conditions (RTA). It is generally used for the (re)design or in-depth analysis of workstations and tasks [14]. The OCRA checklist, based on the OCRA index, is simpler to apply and is generally recommended for the initial screening of workstations [17].

As in the Lifting Index and in the Risk Index, for the OCRA index the level of risk is measured through a characteristic work task variable: for manual material handling tasks the weight to be handled, for OCRA the frequency of technical actions in the shift:

$$OCRA\,Index = \frac{Actual\,technical\,actions\,in\,the\,shift\,(ATA)}{Number\,of\;reference\,technical\,actions\,in\,the\,shift\,(RTA)}$$

To compute RTA, a reference number of technical actions per unit time is set in ideal conditions. Multipliers are then used to account for working conditions other than optimal.

$$RTA = CF \times FoM \times PoM \times \mathrm{Re}\,M \times AdM \times D \times DuM \times RcM$$

where:

- CF, the constant of frequency of technical actions, is set to 30 actions/min. This would represent a safe number of repetitive operations under ideal working conditions;
- FoM, the force multiplier, which is one under the ideal conditions set in EN 1005-3; else FoM values are given in relation to the force perceived by the worker (Borg scale);
- PoM, the posture multiplier, which is one under the ideal conditions set in EN 1005-4; else PoM values are given depending on the degree of joint deviation from neutral posture and of exposure time;
- ReM, the repetitiveness multiplier, which depends on the level of stereotypy within the cycle, where stereotypy considers two elements to define the risk level: duration of repetitive actions with respect to the work cycle and total cycle time;
- AdM, the additional multiplier, which considers the presence of additional risk factors (examples are the use of inadequate gloves, of vibrating tools or the fact that the work pace is completely set by the machine);
- D is the duration, in minutes, of the analyzed manual repetitive task;
- DuM, the duration multiplier, which considers the overall duration of manual repetitive work. The multiplier allows to take into account working conditions that differ from the standard 8 h work shift (regularly working over-time, part-time work, repetitive manual tasks for only a part of a shift);
- RcM, the recovery periods multiplier, which takes into account the number and distribution of breaks within the work shift.

Whole body risk assessment of work tasks in the car assembly: the AAWS and EAWS Methods

The pieces of information on the ergonomics of the workplace, which may be obtained through the risk assessment methods cited by the legislation, mainly concern manual material handling either of substantial loads, as in lifting and carrying, whole body pushing and pulling activities, or of low loads manipulated at high frequency. However, as frequently suggested in the literature, a multi method risk evaluation should be applied to obtain a more global picture of the risk of the workplace [18,19]. Moreover, overall body risk evaluation should be promoted whenever possible, as in many practical situations the worker attends to tasks that have different components of risk which may involve static postures, action forces, manual material handling as well as repetitive movements.

This is typically the case of work tasks in the car assembly, which are characterized by unfavourable working postures, action forces and material handling. Vehicle geometry is responsible for imposed working postures in the form of (lateral) bending and twisting of the trunk and extension of the arms. The whole body should generally be considered. Other factors can include the need to apply strong forces, potentially heavy stress on the finger-hand-arm system from application of strong action forces and repetitive movements.

In the first years of 2000, the screening tool AAWS (Automotive Assembly Work-Sheet) was specifically developed by the Ergonomics Institute of Darmstadt University of Technology (IAD), for the automotive sector on the basis of several joint research projects with German Automotive Industries. AAWS has been developed to comply with German and international legal requirements for healthy and safety at work with special reference to European Legislation [20].

The ergonomic risk assessment through AAWS is relative to an overall evaluation of the working task. Manual material handling, repetitive actions, awkward postures and level of action forces are considered. Ergonomic load points of AAWS are granted for ergonomic unfavourable conditions.

In following years, IAD developed a second ergonomic screening tool known as EAWS (European Assembly Work-Sheet). Evolved from AAWS to comply with all parts of the EN 1005 standard and the corresponding ISO standards, the structure of EAWS is similar to that of AAWS [21,22]. EAWS has an additional section, section 4, relating to the upper limbs. Authors recommend application primarily to short cyclic work (up to 5 minutes), where long-lasting fatigue-generating load situations as well as peak loads are absent [23].

Risk evaluation through EAWS is extended to repetitive movements and provides two index scores as output: one index relating to the whole body risk exposure as in AAWS and a second index relating to upper limbs risk exposure. For the assessment to be acceptable, both index scores need to lie in the green region, i.e. signalling that the task entails negligible risks for muskolo-skeletal problems and should be manageable for all healthy workers.

A primary value of EAWS is the holistic approach to risk analysis and the attempt made by the method developers to taking into consideration the interconnection among the risk factors of the whole body. A second element of interest is the method applicability for risk estimation in early design phase in the project development process.

3. PROCESS ERGONOMICS IN PROJECT DEVELOPMENT

Anticipating the ergonomic analysis as early as possible in project development is fundamental to reduce ergonomic critical issues in the plants. In this way, problems may be designed out of the product and process before reaching the operation phase. However, for such proactive process to be successful, it is crucial that all parts of product and process development are linked to and communicate with the ergonomics process.

Experience shows that it is not enough to build technically good ergonomic workplaces because of the chain of coordinated factors from design to production. A comprehensive approach is needed if good results are to be achieved [24,25].

Figure 2 clarifies an important aspect that must be considered when running an ergonomic analysis. Each main step of a new project development is characterized by an increasing level of complexity but also of knowledge and definition of the project itself. Not all risk assessment methods are applicable at the different stages of project development. Depending on the phase, different data may constitute the basis of the analysis.

In the early stage of design, the level of knowledge does not allow for a very detailed risk analysis as rough geometric data (digital data mostly) are available. Therefore, at this stage simple tools are advisable to analyze critical ergonomic issues related to posture, action forces and material handling.

It is only in the industrialization phase that more detailed design data, as for geometries, materials and location of parts, become available thus allowing for a detailed ergonomic analysis of postures, action forces and material handling. Some product changes are still possible, even though the cost of changes increases as the project progresses. At the industrialization phase, time information become available. Work organization may be improved taking into consideration the level of biomechanical workload exposure.

At the level of production, planned procedures are already set with limited possibilities to change the process. At this stage, observational methods may be applied at their fullest in compliance to safety laws and technical standards.

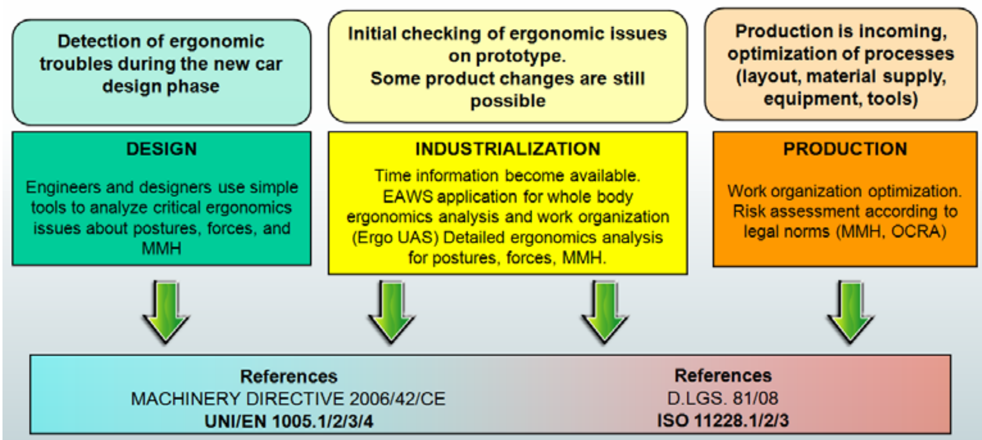


***Figure 2** Ergonomics approach in the main steps of a new project development at FGA*

Table 2 summarizes application of the different risk assessment methods and technical standard, as it pertains to the three stages of a new project development in Fiat Group Automobiles (FGA). Compliance to safety laws is carried out through applicable technical standards in the design phase (EN 1005) and re-evaluated in the production phase at the observational level (ISO 11228); an intermediate and voluntary step of risk evaluation may be added during the industrialization phase through the EAWS method. Assessment of the biomechanical workload exposure at this stage may also provide pieces of information for work organization and line balancing [18].

Table 2 *Application of risk assessment methods and technical standards at FGA*

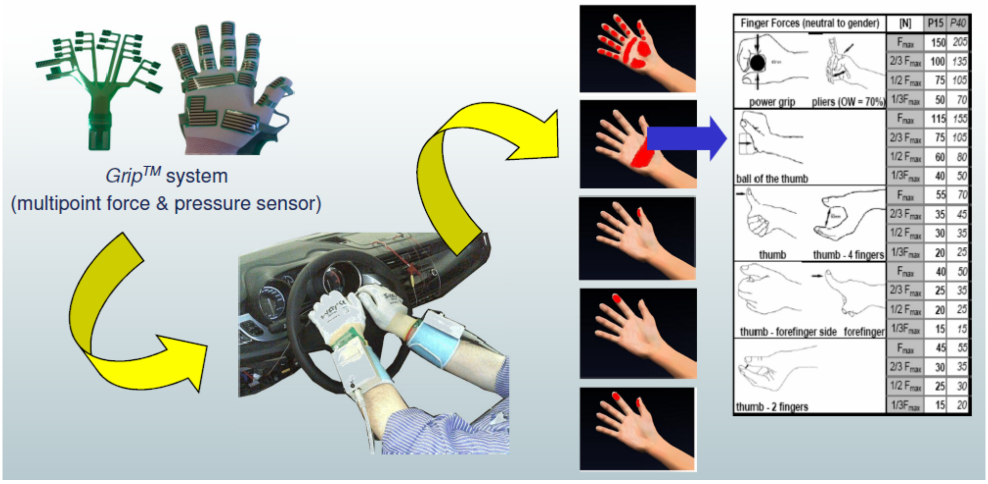
TYPE OF ANALYSIS	APPLICATION	METHODS (STANDARDS)	ITALIAN/EUROPEAN SAFETY LAWS
Postural Analysis	Design phase	(EN 1005-4)	Mandatory
Forces	Design Pahse	(EN 1005-3)	Mandatory
Manual Material Handling	Design Phase	Lifting Index NIOSH, Snook & Ciriello Tables (EN 1005-2))	Mandatory
Whole body	Industrialization phase	EAWS (EN 1005-1,2,3,4,5)	-
Manual Material Handling	Production phase	Lifting Index NIOSH, Snook & Ciriello Tables (ISO 11228-1,2))	Mandatory
Handling of low loads at high frequency	Production phase	OCRA (ISO 11228-3; EN 1005-5)	Mandatory

A pro-active ergonomic approach calls for a preliminary estimation of physical workload in the design phase, and a successive measurement when the workstation is in place. Body postures and forces are fundamental biomechanical parameters for ergonomics assessment and are closely linked together. Awkward postures are known to conduce to pain and should be avoided; non-neutral postures also limit the maximum level of force that can be sustained by a given articulation, and so the maximum level of effort that can be exerted by the related muscles.

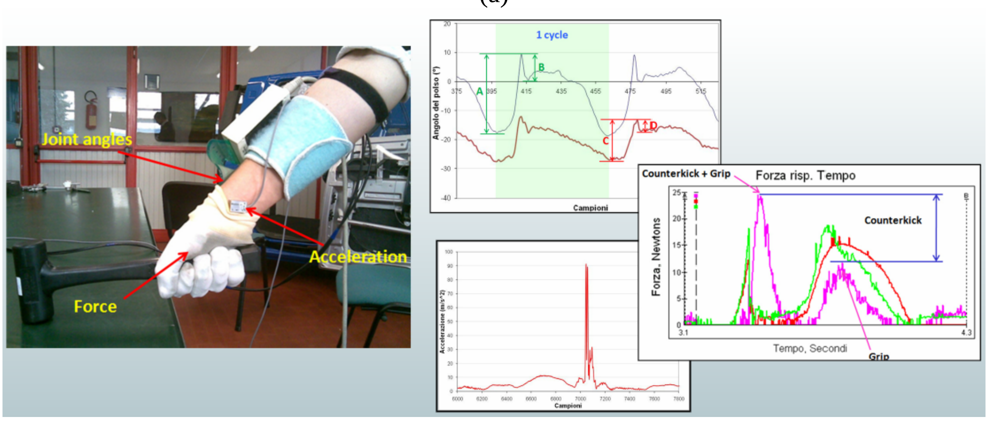
The Three-Dimensional Static Strength Predic-tion Program (3DSSPP) designed by researchers at the University of Michigan’s Center for Ergonomics is now a commercial software, available since 1989, that allow designers to manipulate the posture of a three-dimensional human form model with evaluative algorithms derived from static strength of approximately 3000 healthy college students and workers, ranging in age from 17 to 65 years [26]. The algorithms consider the posture, selected anthropometry, gender and forces on the hands to determine spinal compression forces, joint static strength capabilities and balance [27]. NIOSH guidelines are implemented for joint strength capabilities and back compression limits.

Analysis capabilities have been implemented as part of workplace design; the simulation is not intended for computing the biomechanical workload on a specific worker, but rather to verify task feasibility and assess information on strength capability requirements at the earliest stage of design. Typically, the population used is composed by 5th, 50th and 95th percentile of both genders; for each of the six defined anthropometries, specific postures within each task are simulated and parameters of joint moments and postures can be computed, once forces on hands are introduced as input parameters in the model.

From the engineering point of view, objective measures are a fundamental requirement to perform a robust and repetitive physical workload evaluation. While direct measurement of articular moments is quite impractical, especially during operator work, direct measurement of external hand forces, despite of significant complexity, may be approached.



(a)



(b)

Figure 3 *Examples of experimental activities for characterization of finger/hand forces (a) and work tools(b)*

Figure 3 depicts two activities carried out thanks to the cooperation with Fiat Research Center (CRF). Experimental set-ups for direct measurement of hand forces, involving the use of thin, high-resolution, tactile pressure sensors, are being investigated and tested. Calibration methods and experimental procedures are being developed as well as data processing techniques. Twin axes goniometer, that simultaneously measures angles in two planes of movement, are used to get information on wrist joint angles in flexion-extension as well as in radial –ulnar deviation.

Meanwhile, a laboratory facility is being build and equipped next to the Mirafiori Plant in Torino. The lab should become fully operational within the upcoming year. By reproducing a workcell in the lab, it will be possible to perform product and process feasibility analysis, to test compliance of product components to specifications as well as to acquire the experimental data that may be necessary for work task ergonomic characterization.

Virtual workplace optimization through computer-aided simulation techniques may also bring important advantages, allowing for visualization of postures and movement of the human operator at earliest stage of design (Figure 4). In the computer 3D simulation techniques, the human operator is replaced by an anthropometrical articulated representation called “mannequin”. A number of ergonomics simulation tools have been developed using this approach and are used at the different steps of project development [28,29]

At a first step, simulation of manual assembly tasks allows for checking human movements and postures in order to evaluate general feasibility of the task and risks, mainly from the stand point of reach ability, space demands and visual needs for various anthropometries. Implementation of objective ergonomics methods is a following and necessary step for testing the workplace with respect to infringements upon threshold values of applicable standards and guidelines [30].

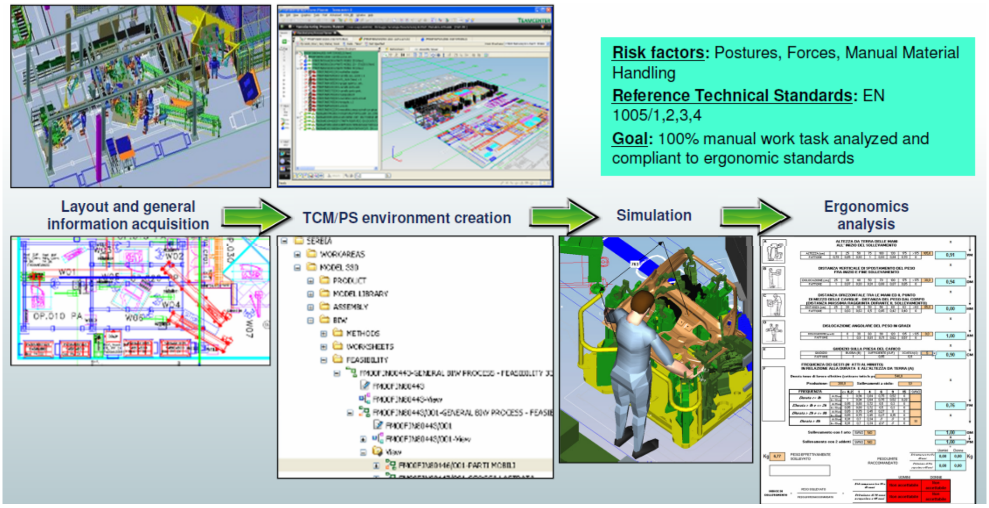


Figure 4 *An example of virtual simulation for ergonomic analysis in FGA*

4. THE NECESSARY ROLE OF EDUCATION

An objection sometimes moved against product designers is that they tend to focus on product performance and design, often overlooking the impact design choices have on the workers that will actually manufacture the product.

In 2008, FGA and Politecnico signed an agreement aimed at enhancing active cooperation in the area of ergonomics between the industrial world and the academia as well as at promoting the introduction of ergonomics workplace design at the curricular level of future production engineers and designers. The aim has being pursued through multiple initiatives: activation of courses on ergonomics, grant of Ph.D. scholarships in ergonomics and participation in joint research projects. In all initiatives, active cooperation with the Department of Occupational Medicine at Università degli Studi di Torino was pursued for a comprehensive view of ergonomic matters [31].

Following the agreement, a 60 hour course "Ergonomics for Manufacturing Systems", was activated within the Master Degree in Automotive Engineering. The course, soon to be at its fifth edition, has seen an increasing number of students enrolling, with the participation of international students as well as locals. The course started as an elective course and is now compulsory for students with a minor in management of industrial processes.

The course covers some basic knowledge on main physical, sensory and cognitive capabilities, anthropometry, and biomechanical modelling. Main emphasis is given to manual material handling, hand intensive tasks and associated musculoskeletal disorders, methods and tools of risk assessment. Few hours are devoted to illustrate health and safety legislation, technical standards as well as the principles of work measurement techniques. Class tutorials, consisting in the analysis of case studies and in exercises for risk assessment method application, are of significant help for students in learning the course contents. Finally, the course introduces the principles of human-machine interaction and the concepts of usability of tools and equipments.

In essence, the course aims at providing the basic knowledge on ergonomics for manufacturing systems to future production engineers as well as process and product designers, emphasizing how a better involvement of the human element in the design of manufacturing processes and operation management may reduce the physical and mental workload sustained by the operator, improve his/her well-being and the system productivity (in the respect of gender issues and of people with special needs). Since activation of the course, the number of students focusing their Master thesis on ergonomic aspects has steadily increased. In many cases, the final work was developed within a six month student internship at FGA.

More recently, a course on ergonomics and workplace design has been activated for Ph.D. students, coming from the different areas of engineering and industrial design, with the aim of spreading the ergonomics culture beyond traditional boundaries. Likewise, the course is now offered within the Master in Safety Engineering and Risk Analysis, traditionally addressed to civil and plant engineers.

Three-year Ph.D. scholarships have been granted following the cooperation agreement and participation in joint research projects has also been pursued. The projects, run at the regional level, involved the three local universities, trade unions as well as employers' associations. A first research project, developed between 2009 and 2010, focused on the applicability of ergonomics in the workplace; in particular, on a proposal for an integrated and interdisciplinary approach to ergonomics and risk assessment which combines physical, cognitive as well as environment ergonomics. A second project supported by INAIL (Italian Workers' Compensation Authority) is now in place, seeking to develop a toolkit for a holistic workplace risk assessment. In addition to standard observational methods, attention is posed at risk estimation in the design phase, so to ensure early evaluation of new products and in production planning. As in the first project, results will be made public through the project website www.ergonomia.corep.it, hopefully helping to spread the ergonomic culture in the workplace and to aid compliance with health and safety legislation.

5. CONCLUSIONS

In manufacturing, control of risks at manual workplaces is a requirement commanded by legislation, care for health of workers and economic considerations. End target of ergonomics is to combine the human and economic dimension of sustainability and social responsibility by optimizing system performance and human well-being.

Ergonomics can be involved in all stages of planning, design, implementation, evaluation, maintenance, redesign and continuous improvement of work systems. Yet, anticipating the ergonomic analysis as early as possible in project development is fundamental to reduce ergonomic critical issues in the plants.

For such proactive process to be successful, it is crucial that all parts of product and process development are linked to and communicate with the ergonomics process.

Education plays a necessary role to spread the ergonomic culture at the workplace. Close cooperation between academia and industry may help integrating different perspectives and hopefully closing the gap between industry, practitioners and researchers.

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