
Exposure Assessment of Upper Limb Repetitive Movements: A Consensus Document

Developed by the Technical Committee on Musculoskeletal Disorders of the International Ergonomics Association (IEA) and endorsed by the International Commission on Occupational Health (ICOH)

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1. INTRODUCTION

1.1. Aim

This consensus document, while taking into consideration the most recent and significant contributions in the literature, intends to supply a set of definitions, criteria, and procedures useful to describe and, wherever possible, to assess the work conditions that can represent a physical overload for the different structures and segments of the upper limbs. The consequences of physical overload are represented by work-related musculoskeletal disorders (Hagberg *et al.* 1995).

The document is aimed at all the operators, i.e. occupational doctors but mainly technicians, who are, or will be, involved in the prevention of work-related upper limbs musculoskeletal disorders.

From this point of view, the document intends to provide methods and procedures (for an exposure assessment) easily applicable in the field, not requiring sophisticated instrumentation and, when possible, based on observation procedures.

The proposed methods shall be based as far as possible on knowledge and data from scientific literature: when these are contradictory or deficient, reference will be made to standards or pre-standards issued by national and international agencies and bodies, with the experience of researchers involved and common sense.

From time to time it shall be clarified on which (more or less consolidated) basis the different result analysis and interpretation procedures are proposed.

The “guiding principle” that brought about all the choices reported in the document can be summarized in a few lines of the International Code of Ethics of Occupational Health Professionals prepared by the International Commission on Occupational Health (ICOH 1992) “Special consideration should be given to the rapid application of simple preventive measures which are cost-effective, technically sound and easily implemented. Further investigations must check whether these measures are efficient and a more complete solution must be recommended, where necessary. When doubts exist about the severity of an occupational hazard, prudent precautionary action should be taken immediately.”

Potential users increasingly demand an easily applicable method for description and assessment of work with repetitive movements, avoiding the risk of “trying to measure everything”, “interpreting little” and “changing nothing”.

In Europe this is a result of the new legislation (particularly, European Economic Community (EEC) directive 391/90/CEE) which requires employers to evaluate work hazards in their companies and reduce them if necessary. The European Union’s “Machine Directive” also deals with this topic, by introducing the need to provide machine designers and manufacturers with easily applied methods with which to evaluate potential health risk factors connected with using these machines.

The group intends to give a response, even if there are still uncertainties from a strictly scientific standpoint; however, the group commits itself to perform subsequent validations especially of as yet unconsolidated issues. Therefore, what is proposed is not a “rigid pattern” but, once some reference points have been

set, it is intended as a dynamic tool able to seek in time the best point of equilibrium between knowledge from research and application requirements.

This document focuses specifically on identification of risk factors and describes some of the methods that have been developed for evaluating them. There is a rapidly developing body of literature on job analysis and as yet no agreement on a single best way to analyze jobs. It is the committee's belief that the appropriate methods depend on the reason for the analysis, e.g. walk through inspection, evaluation of a specific tool or work method, or analysis of a problem job. The appropriate methods will also vary from one work situation to another, e.g. office where workers are performing keyboard tasks or foundry where workers are using powered grinders. Professional judgement is required to select the appropriate methods. Analysis and design of jobs should be integrated into an ongoing ergonomics program that includes management commitment, employee involvement, hazard identification and control, training, health surveillance, and medical case management.

The aim of this section is not a complete overview of the literature. It simply intends to direct readers towards such studies that represent essential contributions for the operational choices which are then suggested by the authors of this study.

In 1987, C.G. Drury (Drury 1987) discussed a method for the biomechanical assessment of pathologies due to repetitive movements, and focused on three main factors (force, frequency, and posture); he suggested a description and assessment method which counts the daily number of "hazardous movements" for the body, and particularly for the wrist.

In 1988, V. Putz Anderson published an interesting book in which he systematically listed all the practical and theoretical knowledge, which was available at the time, on the control and management of cumulative trauma disorders (CTDs) (Putz Anderson 1988). Amongst other things, the book postulates a "risk model" for CTDs, based on the interaction of four main factors: repetitiveness, force, posture, recovery time.

In 1986—7, Silverstein, Fine and Armstrong (Silverstein *et al.* 1986, 1987) highlighted the connection between repetition and force risk factors and Cumulative Trauma Disorders (particularly Carpal Tunnel Syndrome). They also threw light on the fact that there is a synergistic mechanism between the two factors under consideration.

In 1992, Winkel and Westgard suggested some guidelines for the study of occupational risk factors — and of individual ones — related to alterations of the cervical and scapulohumeral region (Winkel and Westgaard 1992).

In 1993, a large group of authors who were part of an ICOH working group, mainly Scandinavian and American, presented a conceptual model for the interpretation of the development of occupational musculoskeletal disorders of the neck and upper limbs (Armstrong *et al.* 1993).

Again in 1993, Tanaka and McGlothlin, two NIOSH researchers, presented a conceptual model for the study and prevention of the occupational carpal tunnel syndrome (CTS) (Tanaka and McGlothlin 1993). In their method, the exposure limit required is determined by the repetitiveness of movements, by the force used, and by the postural deviations of the joint involved, the wrist in this case.

In 1993, McAtamney and Corlett proposed the Rapid Upper

Limb Assessment (RULA) method (McAtamney and Corlett 1993) in which upper limb risk exposure was evaluated using a simple description of the posture, force, and repetitiveness of the muscular action. They also proposed a procedure to calculate a synthetic index.

Guidelines for "practitioners" were presented and discussed by Kilbom in 1994, for the analysis and assessment of repetitive tasks for the upper limbs (Kilbom 1994).

This is an extremely important review, both theoretically and practically, and supplies useful suggestions both for the definition of repetitive tasks, and for the classification of the different issues to consider during analysis.

Frequency of movement is pointed out as being of particular importance for the characterization of risk. For each body region (hands, wrist, elbow, shoulder), indications are given on the frequency limits of similar movements showing a high risk for upper limb injuries where such frequencies are exceeded.

With respect to action frequency, the existence of other overloading factors (high force, high static load, speed, extreme postures, duration of exposure) is considered as being an amplification of the risk level.

In 1995, the contributions of a qualified panel of authors were summarized in a volume devoted to work-related musculoskeletal disorders (WMSDs) (Hagberg *et al.* 1995). Starting from an analysis of the best designed studies on the subject, the book examines the different elements representing occupational risks which could be a cause of the various pathologies of the upper limbs, and possible measurement and analysis methods are indicated for each of the elements considered.

Moore and Garg suggested a model to analyze jobs for risk of distal upper extremity disorders. It is based on the measurement of six variables: force, action frequency, posture, recovery time within a single cycle, speed of work, daily duration (Moore and Garg 1995).

More recently, NIOSH's Center for Disease Control and Prevention published "Musculoskeletal Disorders and Workplace Factors: A Critical Review of Epidemiological Evidence for WMSDs of the Neck, Upper Extremity and Low Back." One of the things that this volume provides is a critical report of studies used to show the association between certain working risk factors (particularly repetitiveness, force, posture and vibration) and individual upper limb pathologies.

There are also various documents prepared by national bodies, institutes, and by International Standards agencies. These represent useful references for the definition of description and analysis procedures and criteria when dealing with tasks that present biomechanical overload for the upper limbs. Among these, the following deserve mention:

- the "Code of Practice Occupational Overuse Syndrome" issued by the Australian Health and Safety Commission in 1988 (Victorian Occupational HSC 1988);
- the "Ergonomic Program Management Guidelines for Meatpacking Plants", issued by the OSHA, USA, in 1991 (OSHA 1991);
- the standard plan for the control of CTDs which is being drafted by American National Standard Institute (ANSI), a USA standards agency (ANSI z—365 Draft Control of CTD—PONT. 1 upper extremity (ANSI 1995);

- the OSHA draft standard “Ergonomic Protection Standard” (Schneider, S. 1995).
- The draft standards pr-EN 1005/3 (Committee European Normative — CEN 1997) and pr-EN 1005/4 (CEN 1997) concerning, respectively, “Safety of Machinery, Human Physical Performance. Recommended force limits for machinery operation” and “Safety of Machinery, Human Physical Performance. Evaluation of Working Postures in Relation to Machinery.”
- The draft standards ISO/DIS 11226 (1998): “Evaluation of working postures”.
- Sjøgaard G., Fallentin N. “*Exposure assessment in repetitive monotonous jobs: Danish national strategies for preventing work-related musculoskeletal disorders*”. Schriftenreihe der Bundesanstalt für Arbeitsschutz. Tagungsbericht 10. “*Problems and progress in assessing physical load and musculoskeletal disorders*”. Dortmund: Bundesanstalt für Arbeitsschutz: 73–81 1996.
- Circular letter No. 5/1994. “Monotonous repetitive work. A model for mapping and evaluating repetitive monotonous work”. Danish Working Environment Service: 1–12 1994 (in Danish).

Beyond the specific objectives, these drafts continuously relate the evaluation of force and posture to the other factors. Thus, the force limits are related to action frequency, speed, and work duration. The acceptability of certain postures and movements of the various upper limb segments is established by the duration for which they are maintained and (in the case of movement) to the action frequency.

In summing up this report, room must be given to the checklists that are so often seen in the medical literature, although this is not the occasion to propose a detailed analytical review. In general terms, however, it can be said that checklists have proved useful, either in particular application contexts (e.g. industrial sectors with assembly lines in which the workers carry out a single task) or, in establishing the presence/absence of a job that is “problematic” for the upper limbs (without evaluating the merit of the individual risk factors and the possibility of reducing them).

This study takes into consideration several proposals derived from the most authoritative checklists. At the same time, it searches for models to describe and evaluate each of the main risk factors considered in those checklists.

2. ASSESSMENT GENERAL MODEL AND DEFINITIONS

The description and assessment general model, concerning all exposed workers in a given situation, is aimed at evaluating four main collective risk factors: repetitiveness, high force, awkward posture and movements, lack of proper recovery periods. Such factors shall be assessed as a function of time (mainly considering respective duration).

In addition to these factors, others, grouped under the term “additional factors”, should be considered. These are mechanical factors (e.g. vibrations, localized mechanical compressions), environmental factors (e.g. exposure to cold) and organizational factors (e.g. pre-established and non-adjustable rhythms) for which there is evidence of causal or aggravating relationship with work-related musculoskeletal disorders of the upper limbs: the list of such factors is open.

Each identified risk factor is to be properly described and classified. This allows, on the one hand, the identification of possible requirements and preliminary preventive intervention for each factor and, on the other hand, eventually, to consider all the factors contributing to the overall “exposure” in a general and mutually integrated frame. From this viewpoint “numerical” or “categorical” classifications of results may be useful for an easier management of results, even if it is important to avoid the sense of an overt objectivity of methods whose classification criteria may still be empirical or experimental ones.

To this end, the following definitions are important:

- The work is composed of one or more *tasks*; these are definite activities (such as the stitching of clothing, the loading or unloading of pallets, etc), that can occur one or more times in one work shift;
- within a single task, several *cycles* can be identified. Cycles are sequences of technical actions, which are repeated over and over, always the same way. In general terms, cycles describe the completion of an operation on product or, sometimes, the completion of a product unit.
- within each cycle, several *technical actions* can be identified. These are elementary operations that enable the completion of the cycle operational requirements. They may imply a mechanical activity, such as turning, pushing, cutting, etc, or a control activity, e.g. checking for faults, etc. In this case, the action is not necessarily identified with the single body segment movement, but rather as a group of movements, by one or more body segments, which enable the completion of an elementary operation.

There is a terminological problem in defining a technical action: in fact, it is substantially attributable to the concept of “*Therblig*” (Barnes 1958, 1968) “work element” in some literature sources, or “micromotions and exertions” in the ANSI 2-365 (1995) draft. To solve this terminological problem, it was decided to keep the term “technical action” which is immediately understandable by worksite technical staff. Related examples (picking, shifting, moving, turning) should eliminate any doubtful interpretation. Table 1 lists the main terms used in this document, together with the definitions that best fit the authors operational choices for exposure assessment.

The suggested procedure for assessing the risk should follow the general phases listed hereunder:

- pinpointing the typical tasks of any job, and — among them — those which take place in repetitive and equal cycles for significant lengths of time;
- finding the sequence of technical actions in the representative cycles of each task;
- describing and classifying the risk factors within each cycle (repetitiveness, force, posture, additional factors);
- reassembling of the data concerning the cycles in each task during the whole work shift, taking into consideration the duration and sequences of the different tasks and of the recovery periods;
- brief and structured assessment of the risk factors for the job as a whole.

3. ORGANIZATIONAL ANALYSIS

Organizational analysis should come before the analysis of the

Table 1. Main definitions of recurring terms used in exposure assessment.

Organized work:
the organized grouping of work activities that are carried out within a single working shift; it may be composed of one or more tasks.

Task:
specific working activity aimed at obtaining a specific operational result
The following tasks are identified:
REPETITIVE TASKS: characterized by repeated cycles with mechanical actions
NON-REPETITIVE TASKS: characterized by the presence of non-cyclical mechanical actions

Cycle:
a sequence of technical, mainly mechanical, actions, that is repeated over and over, always in the same way.

Technical action (mechanical):
an action that implies a mechanical activity; not necessarily to be identified with the single joint movement, but rather with the complex movements of one or more body regions that enable the completion of an elementary operation

Potential risk factors

Repetitiveness:
the presence of events (i.e. cycles, technical actions) that are repeated in time, always in the same way.

Frequency:
number of technical (mechanical) actions per given time units (no. of actions per minute)
High frequency is the related risk factor.

Force:
the exerted force required by the worker for the execution of the technical actions.

Posture:
the whole postures and movements used by each of the main joints of the upper limb to execute the sequence of technical actions that characterise a cycle.

Awkward posture: hazardous postures for the main joints of the upper limbs.

Recovery period:
period of time between or within cycles during which no repetitive mechanical actions are carried out. It consists of relatively long pauses after a period of mechanical actions, during which the metabolic and mechanical recovery of the muscle can take place. Lack of recovery is the related risk factor.

Additional risk factors:
additional risk factors may be present in repetitive tasks but are neither necessary nor always present. Their type, intensity, and duration lead to an increased level of overall exposure.

four main risk factors and of the additional factors. It is essential to focus on the *real task duration and repetitive tasks*, and on the existence and distribution of *recovery periods*.

The first phase of the analysis is finding the distribution of work times and pauses within the work shift(s).

In this way it is possible to find the duration and distribution of the macro-pauses (RECOVERY PERIODS).

The organized work shift may consist of one or more working tasks.

In turn, each task may be characterized by cycles or by other types of execution.

If the task is characterized by cycles with mechanical actions, it will be defined as a REPETITIVE TASK.

If it is characterized by check operations (examination, inspection) without movements or awkward postures, and

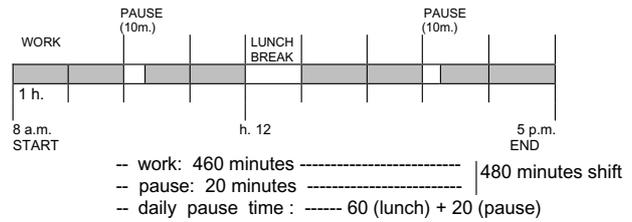


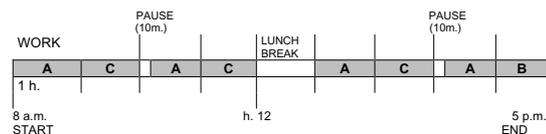
Figure 1. Definition of repetitive task.

therefore without mechanical actions, it will be defined as a recovery for the upper limbs.

The tasks with non-repetitive mechanical actions remain and shall be defined as NON-REPETITIVE TASKS (but not “recovery periods”).

The number of foreseen cycles within a REPETITIVE TASK, and the net duration of each cycle, must be counted at this point.

TASK	DESCRIPTION	MIN. IN SHIFT AND MAIN CHARACTERISTICS	TASK TYPE
TASK A	PISTON ASSEMBLY	220	REPETITIVE TASK
TASK B	LINE MAINTENANCE OPERATIONS	60	NON-REPETITIVE TASK
TASK C	LINE VISUAL CONTROL	180	RECOVERY
PAUSE	2 x 10 MIN. EACH 60 MIN. (LUNCH)	80	RECOVERY
			TOTAL 480 MIN. WORK (+ 60 MIN. LUNCH)



Note: periods of “non-working” in the order of minutes.

Figure 2. Definition of non-repetitive task.

The number of cycles often coincides with the number of pieces to be worked in each shift.

4. RISK FACTORS

TASK A described in Example 2	→ 440 pistons must be assembled in 220 min in the 8-hour shift
	→ the assembly of each piston is to be considered as a single cycle
	→ the cycle duration is 30 sec. (440 pistons in 220 min. net)

Figure 3. Definition of cycle time.

4.1. Repetitiveness: frequency

This is probably the risk factor of greatest importance in many jobs in industry, so much so that the syndromes of specific interest have often been defined through this element (repetitive strain injuries). The characterization of repetitiveness can be used to discriminate the tasks that must be assessed. To this end, the presence of a repetitive task for the upper limbs can be defined as the consecutive activity, lasting at least one hour, in which the subject carries out work cycles similar to each other and of relatively brief duration (a few minutes at maximum). The cycles require the carrying out of mechanical actions.

Once repetitive tasks are submitted to analysis, there is the more important problem of quantifying and assessing repetitiveness. In the literature, a definition of repetitiveness on

the basis of cycle duration can frequently be found. High repetitiveness, in particular, is postulated with cycles lasting less than 30 seconds (Silverstein *et al.* 1987).

This same proposal is completed by stating that high repetitiveness occurs when over 50% of the cycle time is spent in performing the same type of action. It is to be noticed, however, that it is possible that very short cycles do not require very frequent gestures and movements, and that longer cycles are carried out with a high frequency of actions. Since the development mechanism of tendon pathologies seems to be related to movement frequency, then action frequency is a more accurate estimation factor of this risk element.

Measuring the frequency of the single joint movements would be the best thing for assessment, as some authors suggest. In fact, the highest risk occurs when the same type of movement is frequently repeated by the same joint. Obviously, a direct measurement of joint movement frequency is not always feasible in the field. It would require the measurement of the frequency of each type of movement (flexion, extension, adduction, abduction, etc.) for each of the main joints, and for both upper limbs.

In this proposal repetitiveness is measured, on the one hand, by counting, within the cycle, the number of technical actions performed by the upper limbs and, on the other hand (see, hereafter, analysis of postures and movements), by identifying, for each action, how many times (or for how long) it involves a given posture or movement of each main segment/joint of the upper limbs (hand, wrist, elbow, shoulder).

A description of the technical actions often requires the filming of the job, which must then be reviewed in slow motion. When the cycles are very short (few seconds), a direct observation at the workplace could work as well as filming. If the task is technically complex, it is extremely useful, indeed often essential, to describe the action sequence with the help of company technical personnel experienced in the task itself. Often, the company already has records available in which the task is described and numbered, and the elements constituting successive technical actions are timed (methods—time measurements).

In order to analyze frequency, the following steps have to be implemented:

(a) Description of the technical actions: reviewing the film in slow motion, all technical actions carried out by the right and left upper limbs, must be listed in order of execution. When the same action is repeated more than once, such as drawing a screw, each repetition of a single action must be counted (i.e. turning four times). When a certain action is carried out repetitively, but not on all pieces (i.e. technical actions for quality control, to be carried out once every 4 pieces or every 20 pieces), then the action described is counted with the relevant fraction (one-fourth or one-twentieth). The technical action sometimes coincides with the joint movement. In this case, when the execution of a simple movement is aimed at the execution of a given technical action, it must be counted as a proper technical action (i.e. use finger flexion to push button). Table 2 gives a description of a brief but complex operating cycle recorded at a working post on an engine assembly line. The actions listed are ascribed to the left and/or right upper limbs in

numerical terms. Actions not necessarily present in every cycle, are specially calculated.

(b) Calculation of action frequency; from the previously described work organization study, the following are already known: net time of repetitive task, number of cycles in repetitive task, duration of each cycle. From the technical action description it is possible to obtain: the number of actions per cycle, and therefore the action frequency in a given time unit: NO. OF ACTIONS PER MINUTE (Table 2). It is also possible to obtain the overall number of actions in the task/tasks, and consequently for the shift. Additional considerations should be also given to the “cyclicality” (i.e. the changing of frequency during the shift: regular, irregular or cumulated) of a job.

4.2. Force

Force more directly represents the biomechanical effort necessary to carry out a given action, or sequence of actions. Force may be described as being external (applied force) or internal (tension developed in the muscle, tendon, and joint tissues). The need to develop force during work-related actions may be related to the moving or the holding still of tools and objects, or to keeping a part of the body in a given position.

The use of force may be related to static actions (static contractions), or to dynamic actions (dynamic contractions). When the first situation occurs, it is generally described as static load, which some authors describe as a “distinct risk element” (Hagberg *et al.* 1995).

In the literature, the need for using force in a repetitive fashion

Table 2. Example of description and calculation of technical action frequency within a complete cycle.

	NUMBER OF ACTIONS IN A COMPLETE CYCLE	
	RIGHT	LEFT
- Pick up and position gasket in bushing lodging	2	
- Use pincers in right hand and hook 1st spring	2	1
- Use pincers in right hand and hook 2nd spring	2	1
- Shift calibre and push button	2	1
* Spring position correction (once every four pieces)		
- Pick up unscrewing tool and position it	2/4	3/4
- Unscrew or screw spring	1/4	1/4
- Put tool down		1/4
* Substitution of broken spring (once every 20 pieces)		
- Pick up unscrewing tool and position it	2/20	3/20
- Unscrew spring (4 times)	4/20	4/20
- Hold tool		1/20
- Pick out broken spring with pincers (2 times)	2/20	
- Pass tool into right hand	1/20	
- Pick up spring and put it on tool	1/20	2/20
- Position spring and screw it in (4 times)	5/20	5/20
- Put tool down		1/20
	Total	9.5 5
No. of pieces per shift	=	2075
Cycle time	=	11.9 sec. per piece
No. of technical actions per cycle: on the right	=	9.5
on the left	=	5.0
Frequency:	Right	$9.5 \times 60 = 47.9 \approx 48$ (action/minute) 11.9
	Left	$5 \times 60 = 25$ (action/minute) 11.9

is indicated as being a risk factor for tendons and muscles. Furthermore, a multiplying interaction has been shown to exist between force and action frequency (Silverstein *et al.* 1986), especially for tendon pathologies and nerve entrapment syndromes.

Force quantification in real life contexts is a problem. Some authors use a semi-quantitative estimation of external force via the weight of the objects being handled. In other cases, the use of mechanical or electronic dynamometers has been suggested. The internal force can be quantified by means of surface electromyography techniques.

Finally, other authors suggest using subjective evaluation methods through psychophysical rating scales. On account of in-field applicability problems, two different procedures are advised for the evaluation of the use of force associated with the technical actions present in one cycle.

4.2.1 Use of dynamometers to assess the force required to carry out a given technical action

This procedure is possible and recommendable for actions involving the use of levers, or components of machines and objects. In these cases it is possible to determine the force required to move a lever, or, if the dynamometer is equipped with the proper interface, to simulate the same working action by the workers involved (cross modality – matching). It is to be noticed however that not all technical actions requiring the use of force can be easily determined by means of dynamometers. Besides the observer should be able to establish which technical actions respectively do or do not require the use of force also by asking the operator for the forceful actions.

In order to evaluate the use of force, it is necessary to compare the results obtained on the field with the ability of a reference working population: relevant data are available either in the literature or can be provided by National or International Standards organizations (refer to Appendix C). Additional information on maximal action force may be obtained from the “force atlas” (Rohmert *et al.* 1994).

4.2.2 Use of psychophysical rating scales

In this case, worker's subjective evaluation is used to determine the physical effort associated with the cycle technical actions. Of the different psychophysical scales available in the literature, reference can be made to the “CR10 Borg scale” for perceived exertion (the category ratio scale for ratings of subjective somatic symptoms including perceived force, where 10 defines the relative maximum) (Borg 1982, 1998).

The use of subjective scales is not free from disadvantages likely to affect their reliability (e.g. non-acceptance of the “subjective” method by some employers, conflicting situations influence of motivation, presence of “pathological” subjects, wrong communication of the subjective evaluation goal).

Despite these objections, it is worth mentioning that this technique, if correctly used, allows researchers to evaluate the effort associated with any technical action. In terms of evaluation, reference values are provided by the scale itself. Besides which, according to some authors (Grant *et al.* 1994), the results of the implementation of Borg's Scale, when used for an adequate number of workers, have turned out to be comparable to those obtained with surface electromyography (value of Borg's Scale x

10 @ percentage value with respect to Maximum Voluntary Contraction MVC as obtained by EMG).

The quantification of the effort as perceived by the whole upper limb should theoretically take place for every single action that makes up a cycle. For practical reasons, the actions that require no, or minimal, muscle involvement could be identified respectively as 0 or 0.5 value in Borg's Scale; then the involvement description procedure could only describe those actions, or groups of actions, that require more force than the minimal amount, always using Borg's Scale.

This procedure, when applied to all workers involved, allows researchers to evaluate the average score among subjects for each technical action by asking for the use of force, as well as the weighed average score for all actions and the whole cycle time.

Finally it is to be emphasized that whatever the method used for the description and assessment of force, it is necessary to evaluate:

- (1) the average level of force required by the whole cycle — referred to as the maximum force capability, it is defined by reference groups or the group of workers involved;
- (2) whether there are in the cycle (and which and how many) technical actions requiring the development of force beyond given levels (peak force)?

It is useful to know also the presence of peaks because the knowledge of average level only can hide their presence.

4.3. Posture and Types of Movements

Upper limb postures and movements during repetitive tasks are of basic importance in contributing towards the risk of various musculoskeletal disorders. A definite agreement is found in literature as to the potential damage coming from extreme postures and movements of each joint, from postures maintained for a long time (even if not extreme) and from specific, highly repetitive movements of the various segments. Moreover, the description of postures and movements of each segment of upper limbs during technical actions of one cycle completes the description of “the repetitiveness” risk factor. The analysis of postures and movements shall be concerned with each single segment of upper limbs (hand, wrist, elbow, shoulder): it is aimed at checking the presence and time pattern in cycle (frequency, duration) of static postures and dynamic movements involving each segment/joint considered.

The description may be more or less analytical but has to be able to appreciate at least the following items:

- (a) Technical actions requiring postures or movements of a single segment beyond a critical level of angular excursion (see below).
- (b) Technical actions involving postures and/or movements which, even within acceptable angular excursion, are maintained or repeated in the same way.
- (c) The duration expressed as a fraction of cycle/task time of each condition reported above.

Joint combination of such description factors (posture/time) will provide the classification of posture effort for each segment considered.

In order to identify the so-called angular excursion critical levels (point (a)), reference is to be made to data and proposals available in the literature.

Table 3. References to the medium/high involvement of joints during dynamic activity.

	RULA (McAtamney et al., 1993)	CEN prEN 1095-4 ISO/CD 11226	OSHA (Schneider S., 1995)	KEYSERLING (Keyserling W.M., 1993)	DRURY (Drury C.G., 1987)	OCCHIPINTI - COLOMBINI (Occhipinti et al., 1996)	ANSI Z-365 (Ansi, 1995)	MOORE - GARG (Moore et al., 1996)
	MEDIUM-HIGH INVOLVEMENT	INVOLVEMENT HIGH MED.	INVOLVEMENT	INVOLVEMENT	HIGH INVOLVEMENT	HIGH INVOLVEMENT	HIGH INVOLVEMENT	HIGH INVOLVEMENT
SHOULDER								
- Flexion	[45° - 90°] (>90°)	> 60° 20-60°	UNSUPPORTED	UNSUPPORTED	+ 94°	+ 80°	UNSUPPORTED	-
- Extension	SUP.20°	IF PRESENT	UPPER LIMBS OR	ELBOW AT MEDIUM	+ 31°	+ 20°	ELBOW AT MEDIUM	-
- Abduction	IF PRESENT	> 60° 20-60°	CHEST HEIGHT	CHEST HEIGHT	+ 67°	+ 45°	CHEST HEIGHT	-
ELBOW								
- Flexion	[60°] [SUP.100°]	IF EXTREME	-	-	+ 71°	+ 60°	IF EXTREME	-
- Supination	CLOSE TO MAX.RANGE	IF EXTREME	IF SPEEDY	IF PRESENT	+39°, + 57°	+ 60°	IF EXTREME	-
WRIST								
- Flexion	[15°] [SUP.15°]	IF EXTREME	SUP.20°	IF	+ 45°	+ 45°	IF EXTREME	+ 30°
- Extension	[15°] [SUP.100°]	IF EXTREME	SUP.30°	PRESENT	+ 50°	+ 45°	IF EXTREME	+ 40°
- Radial deviation	IF PRESENT	IF EXTREME	-	AND	+ 14°	+ 15°	IF PRESENT	-
- Ulnar deviation	IF PRESENT	IF EXTREME	-	EVIDENT	+ 24°	+ 20°	IF PRESENT	+ 20°
HAND								
- Pinch	-	-	IF > 2 POUND LOAD	IF PRESENT	IF PRESENT	DIFFERENT SCORES FOR DIFFERENT TYPES OF PINCH AND GRIP	IF PRESENT	-
- Grip	-	-	IF > 10 POUND LOAD	-	IF PRESENT		-	-
- Keying	-	-	IF FOR LONG TIME	-	-		-	-
- Other fingers movements	-	-	CLICK AND DRAG	TRIGGERING MOTION	-	SPEEDY FINGERS MOVEMENTS	PRESSING WITH THE TIP OF THE FINGERS	-
HOW TO CLASSIFY POSTURE EFFORT								
- STATIC POSTURE	YES	YES	-	-	-	YES	YES	-
- HIGH FREQUENCY	-	YES	-	-	YES	YES	YES	YES
- USE OF FORCE	YES	-	If grip with force	For objects > 2,7 Kg	YES	YES	YES	YES
- DURATION	-	YES	YES (time in the shift)	YES (> 1/3 of cycle time)	YES	YES	YES	YES
- SAME TYPE OF ACTIONS EVERY FEW SECONDS	YES (> 4 times/min.)	-	YES	YES	YES	YES	-	-

Table 3 summarizes some of the main description and classification methods of postures and upper limb movements during repetitive work.

It should be particularly noted that the international literature highlights the need both to describe the awkward postures and to study their duration and frequency (Putz-Anderson 1988; Hagberg *et al.* 1995; Moore and Garg 1995). It is, however, to be emphasized that at this stage it is not important to describe all the postures and movements of the different segments of upper limbs, but rather to focus on those that by typology or excursion level (as well as by duration) are the static postures and/or the movements involving greater effort and also requiring improvement.

On the other hand, the literature provides information on the risk of postures and movements maintained or repeated identically for prolonged times (point (b)). This holds true even if the excursion of such postures and movements does not reach the critical levels evidenced above. In this case, however, the “duration” factor (point (c)) becomes even more important in fixing criticalness of “stereotypy” of specific postures or motions.

4.3.1 Static postures

Static postures are considered critical when:

- they near the extremes of the movement range — independently of the duration
- they result in the body segment being held in an intermediate position within the joint range for a prolonged period of time.

Table 4 shows an original suggestion (Rohmert 1973) of the

use of muscle force in an optimal balance between static load and recovery time.

Static postures may be present both in repetitive and non-repetitive tasks; an investigation is necessary as well. In this case the evaluation criteria are based on the type of 14 postures, continuative maintenance time, adequacy of recovery periods (see Table 4 and section 4.4). Appendix D1 contains the relevant parts of an easily applicable international consensus standard.

4.3.2 Movements

The literature often provides a definition associating movements with duration (or repetitiveness): work cycle less than 30 seconds or the same fundamental work actions performed during more than 50% of the cycle time are to be considered as critical (Silverstein *et al.* 1987). Using the latter criteria it is possible to assert that repetition of the same action in the same joint (stereotypy) is critical when it exceeds 50% of the cycle time, regardless of the size of the movement angle.

Further, the duration seems to be the major factor in view of determining the level of effort associated with movements with critical angular excursion. In this regard, the literature sources are less univocal but for practical purposes reference could be made to a fraction of the cycle equal or above 1/3 (Keyserling *et al.* 1993; Colombini 1998), or to the criteria for which the extreme movements of a single joint should not exceed a frequency of twice a minute; these can be the “rationale” with which to define a significant threshold of effort associated with critical angular excursions.

To obtain an exhaustive description of postural risk it is necessary to cover four operational phases:

Table 4. Rohmert's original suggestion concerning recovery periods (in seconds) for technical actions requiring isometric contractions (equal to or longer than 20 seconds) for applied times and forces.

FORCE (%MVC)	HOLDING DURATION (SEC.)	RECOVERY PERIOD	
up to 20% MVC	20	2	10%
	30	3	10%
	45	7	15%
	120	60	50%
	180	180	100%
	240	480	200%
about 30% MVC	300	1200	400%
	450	2700	600%
	20	10	50%
	40	40	100%
	60	120	200%
about 40% MVC	90	360	400%
	120	720	600%
	150	1200	800%
	20	20	100%
about 50% MVC	30	60	200%
	50	200	400%
	70	420	600%
about 50% MVC	20	40	200%
	30	120	400%
	40	240	600%
	90	720	800%

- (a) a separate description of postures and/or movements by each joint: shoulder, elbow, wrist, hand (type of grip and finger movements) and by type of effort (static, dynamic);
- (b) static postures: observation of static postures close to extreme articular range, during the cycle/task time; observation of static postures in the medium of articular range held for a prolonged period of time; observation of grip positions during cycle/task time.
- (c) joint movements: presence of articular movements, close to the limit of the range of motion during the cycle/task time; repetitive articular movements, due to presence of the same technical actions (independently of the articular range) for at least 50% of cycle time and subsequently of task time.

To allow the technician to make an easier description and classification of the postural effort (type of posture per time), a form is reported in Appendix A (Table 6) with an example of all the major items for each one of the four segments of the upper limb under consideration in order to obtain a postural score. Appendix D2 contains the relevant parts of an easily applicable international consensus standard.

For practical purposes, a significant cycle should be analyzed for each repetitive task. This is better achieved by videotaping.

The video could be reviewed in slow motion to describe and evaluate the effort of each joint segment, making a distinction between right and left side when the effort is asymmetrical.

4.4. Lack of Recovery Periods

The recovery period is a time during which one or more of the muscle groups that are usually involved in the work tasks are basically inactive (macro-pauses). The recovery period is one of the main factors for overall exposure assessment.

The following may be considered as recovery periods:

- (a) work breaks, including the lunch break
- (b) those periods during which tasks are carried out, which do not involve the usual muscle groups
- (c) those periods within a cycle, with actions implying the total rest of the usually active muscle groups; to be defined as macro-pauses, these periods must be at least 15 consecutive seconds; micro-pauses of very short duration indicated as E.G. EMG gabs of at least 0.2 seconds seems to be of major functional significance but are difficult to detect without technical measurements.

The analysis of the recovery periods is first and foremost a check of their duration and distribution within the cycle, and a macroscopic examination of their presence, duration and frequency within the whole shift. With some exceptions (see later), represented by recovery periods for actions implying protracted static contractions, the description and the assessment of recovery periods should be based on the following:

- (a) a description of the actual task sequences involving repetitive movements of the upper limbs, of "light" non-repetitive tasks, and of pauses;
- (b) the frequency of the recovery periods with reference to the actual number of working hours per shift;
- (c) a ratio between the total recovery time and the total working time, in a shift devoted to tasks involving repetitive movements.

The main problem encountered in analyzing recovery periods is the lack of criteria for an adequate assessment (duration, time scheduling).

In this connection, it is worth making the following considerations.

4.4.1 Static actions

As for static actions, classical muscular physiology studies (Rohmert 1973) provide criteria with which to assess the adequacy of recovery periods as an immediate consequence of a static effort (as a function of its intensity, mostly expressed in percentage of the MVC and duration of involvement).

It should be emphasized, however, that such data refer to effect such as performance or, at best, muscular fatigue but is not fully validated when considering major health effects.

While taking into account such deficiencies, the results of these studies are summarized in Table 4. It shows the various degrees of contraction force, as a percentage of MCV, and the various duration of contraction (in seconds); for each, the minimum necessary muscle recovery periods are indicated, both in seconds and as a percentage of the contraction time. The table is self-explanatory.

After each holding condition, and according to the force developed, an adequate recovery period must immediately follow. If such a period is either absent or inadequate, then there is a condition of risk, all the greater with the greater discrepancy between the actual situation and the optimal one. Table 4 is important as a prevention tool; it offers the optimal division between isometric contraction and recovery periods, to be alternated in strict succession. The corollary of the table, as a prevention tool, is that the force required during isometric contractions that last over 20 seconds (maintenance) must never exceed 50% of MCV.

As to using Table 4, if data about % MCV are not available, it is possible to estimate force using Borg CR10 scale.

Also within non-repetitive tasks characterized by the presence of static postures, it is necessary to use adequate RECOVERY TIMES as suggested in Table 4. Appendix D1 contains the relevant parts of an easily applicable, international consensus standard.

4.4.2 Dynamic actions

As for dynamic actions, no adequate studies are available for evaluating the optimum distribution between repetitive work time (with relative levels of muscular and tendinous effort) and recovery time. A partial exception is the case when so-called intermittent static actions are carried out. For this kind of action, reference should be made to the valuable contribution by Bystrom (1991) that established the maximum acceptable work time before it becomes necessary to have a recovery period, considering a given rate of muscular involvement (expressed in % MVC).

In most repetitive tasks, however, upper limbs actions are typically dynamic and, in the absence of consolidated scientific studies, concerning the optimal distribution of recovery periods, it becomes necessary to refer to “rough” and empirical data reported in the literature or in guide documents and standards (Victorian Occ. HSC Australia 1988; ISO TC 159 Draft 1993; Grandjean 1986).

Logically, if not strictly scientifically speaking, all these documents tend to state that:

- (1) work involving repetitive movements of upper limbs cannot be continuously sustained for over one hour without a recovery period;
- (2) the recovery period, within one hour of repetitive work, has to be in the region of 10–20% of working time (that is about 5–10 minutes per hour). These rough indications, still to be perfected, may guide description and assessment methods of RECOVERY TIMES with relation to “dynamic” activities of upper limbs.

An example of how to obtain a score for “lack of recovery period” is described in Appendix B.

4.5. Additional Risk Factors

There are other factors, apart from those already discussed, which are considered to be relevant in the development of WMSDs.

They always have their origin in work and must be taken into consideration whenever assessing exposure. They have been described as additional in this work, but not because they are of secondary importance — rather, because each of them can be either present or absent in the various occupational contexts. For a factor to be considered, it has to have an association with WMSDs’ effects, as well as having a collective impact (that is, on the whole of exposed subjects or on significant groups of them) and not an individual impact (that is, on single subjects). In other terms, factors such as anthropometric measurements, psychological issues, extra work activities of single subjects are not to be considered at this stage of analysis. The additional risk factors may be mechanical, environmental, organizational ones. The list of factors mentioned here (Table 5) is only an indicative one and is not exhaustive: from time to time each operator will decide on the single factors of interest in view of assessing overall exposure.

Table 5. List of possible additional risk factors (not complete).

MECHANICAL	
●	Hand–arm vibrations
●	Extreme precision in positioning objects
●	Localized compression on upper limb structures
●	Use of gloves
●	Rapid or sudden wrenching movements of upper limbs
●	Blows and shocks (such as hammering hard surfaces)
ENVIRONMENTAL	
●	Exposure to cold
●	Exposure to heat
ORGANIZATIONAL	
●	Machine-paced task
●	Incentive payment
●	Routine overtime
●	Working with tight deadlines
●	Sudden peaks of high workload
●	Lack of training

Mechanical and environmental factors can be described and assessed according to the corresponding time pattern (frequency, duration). This allows the definition of the amount of time (both with reference to cycle time and task time) spent with that factor. For assessment purposes, it will be considered that the optimal condition is represented by the absence, or a very limited presence, of each additional factor. Organizational factors can be described according to category classifications (at least as present/absent).

5. OVERALL EXPOSURE ASSESSMENT

An overall exposure assessment of upper limb WMSDs must account for different risk factors, described one by one and classified.

If, in fact, it is true that the simplest and most elementary prevention actions can be already undertaken after a good analysis of each risk factor, it is all the more true that more comprehensive prevention strategies (e.g. priority choices) must be based on the assessment of overall exposure, as determined by the different combination of the risk factors considered. In this regard, the literature even now provides data and convincing hypotheses on the interrelation between some of the considered factors.

The force–repetitiveness ratio was examined in relation to effects (Silverstein 1987) and muscular capability and physiology while taking activity times (duration) into consideration (CEN 1997).

On the other hand, the relationship between possible force development and some postures (or movements) of the hand—forearm segment (Eastman Kodak 1983) are known. In a recent CEN document (CEN – PrEN1005/4 1996) upper limb postures and movements are classified according to action frequency and overall task duration.

In another recent CEN document (CEN – PrEN1005/3 1997), the recommended force values to be developed in different kinds of manual action by upper limbs are provided in relation to variables such as action frequency, action speed, and overall task duration.

In spite of this, it should be stated that at the present state of knowledge there still is a lack of sufficient data to outline an accurate and parametric general model, combining all the risk factors considered, particularly when the issue is to fix the “specific

weight” of each factor in determining the overall exposure level. Accounting for this, we have to emphasize the necessity of having even partially empirical models for a synthetic assessment of overall exposure to the risk factors considered.

Methods and procedures for determining synthetic exposure scores are already available in the literature. Even when using simple checklists (Keyserling *et al.* 1993; Schneider 1995) the analytical process closes with a synthetic score classifying exposure.

When slightly more sophisticated exposure description and assessment methods are used (McAtamney and Corlett 1993; Moore and Garg 1995), models and procedures are, however, provided for calculating synthetic indices to account for risk factors.

A synthetic index has been recently proposed (Colombini 1998) providing a classification of the risk factors considered here (repetitiveness, force, posture, lack of recovery periods, and additional risk factors). This synthetic index model has been the object of positive preliminary tests, through epidemiological studies. It allows a classification of the results in a three-zone model, useful for implementing preventive actions following from the exposure assessment process.

Being well aware that the data supporting the above overall exposure assessment models are still deficient and often empirical, it is recommended that, if used, they should be adopted “critically” when studies are carried out for preventive action and/or for the active health surveillance of workers. In this respect, and with these goals, the following aspects should be considered:

- (a) The exposure indices proposed at present have a methodological value, showing the concept of the integrated evaluation of risk factors.
- (b) Such indices also have a practical value: even if they do not provide an absolute statement of the exposure (and thus of WMSD risk), at least they allow the ranking of exposure levels derived mainly from the combination of the different factors in the different work situations. This allows priority choices of action and intervention. Currently, an index may only be used in combination with health status monitoring (complaints, disorders) of the workers involved, in order to see whether the right action and intervention were chosen.
- (c) The exposure indices proposed here should not be intended as standards or reference values to distinguish safe or hazardous conditions; this should be clearly emphasized to the potential users.
- (d) The exposure indices proposed here, or in the future, need to be validated by laboratory studies, as well as by epidemiological studies (exposure/effect).
- (e) The issue of exposure integrated assessment of upper limb repetitive movements is a crucial problem for future scientific and application developments of ergonomics.
- (f) Finally, it should be emphasized that the exhaustive description and classification of the risk factors associated with a given repetitive task, the quantification of consequent exposure in a concise, albeit approximate, index, and the need to perform parallel studies on the clinical effects on exposed workers, all represent both an opportunity and a commitment to carry out further research and intervention in the field in the near future.

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APPENDICES

In appendices A and B, some risk assessment examples are shown in order to obtain exposure scores. They represent only a hypothesis of simple methods easily applicable in the field. In appendices C and D, information about the assessment of force, posture, and movement in easily applicable, international consensus standards are presented.

The appendices contain examples of practical methods previously used for measuring exposure and assessing risk. The methods presented in appendices A and B have proved useful in field studies and illustrate possible approaches to the analysis of work place risk factors. In addition, force capacity values included in the preliminary CEN standard (PrEN 1005-3) and the evaluation procedure for postures and movements used in ISO/DIS 11226 and prEN 1005-4 are presented in appendices C and D.

Note: The proposed methods available for work place risk assessment purposes are numerous and the examples presented in this appendix are not especially endorsed or recommended by the authors of the consensus document, nor by the IEA Technical Committee.

Appendix A: An example for calculating postural exposure scores (Colombini 1998)

In order to allow the technician to make an easier description and classification of posture effort (type of posture per time), Table 6 reports a form with an example of all the major items for each one of the four segments of the upper limb under consideration.

There are four operational phases in the form:

- A separate description of postures and/or movements by each joint: shoulder, elbow, wrist, hand (type of hold and finger movements), and by type of effort (static, dynamic).
- Static postures: observation of static postures close to extreme articular range, during the cycle/task time (A_3, C_3, D_3); observation of static postures in medium leverage angle held for prolonged period (A_4, C_4); observation of grip positions (D_1) during cycle/task time.
- Joint movements: presence of articular movements, close to the extreme joint excursions during the cycle/task time (A_1, B_1, C_1); repetitive articular movements, due to presence of same technical actions (independently of the articular range) for at least 50% of cycle time and subsequently of task time (A_2, B_2, C_2, D_2).
- Calculation (for each joint) of the postural involvement score within the cycle/task time summing the scores written in the square boxes, checked during the posture analysis.

The posture involvement score is attributed to each joint, taking into account that the presence of a significant effort is given by either of the two minimum scenarios, one for static postures and the other for movements, respectively.

For practical purposes, a significant cycle should be analyzed (preferably by a video) for each repetitive task.

The video could be reviewed in slow motion to describe and evaluate the effort of each joint segment, making a distinction between right and left side when the effort is asymmetrical.

A possible example to obtain a risk score for the lack of recovery periods is shown below.

Example

With the help of Table 6, analyze the work of an operator who picks up a handful of screws with the right hand, and for two-thirds of the cycle fits the screws into their holes, always using the same hand and holding his arms off the table. Cycle time is 15 sec; shift duration is 8 hours.

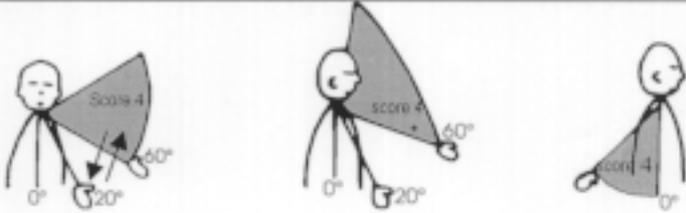
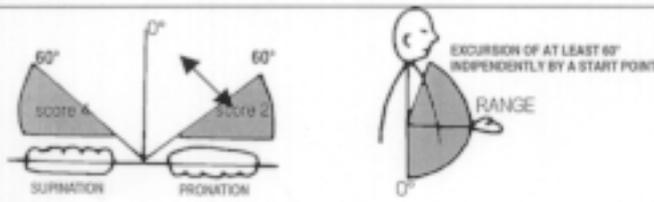
Begin by observing the shoulders.

The operator first takes the screws from a container (abduction/adduction more than 60°) and then keeps the arm in flexion, in a risk area (>60°) for 2/3 of cycle time.

In Table 6, under shoulder sign in A1: 1/3 (score 4), in A3: 2/3 (score 8), in A4 the continuously keeping the arm raised (score 4).

The posture score for the shoulder is 16: in this way critical movements, critical static postures and continuously arm-raised

Table 6: Analysis of upper limb postures as a function of time: a simplified model with an example (example 4)

TASK INVOLVEMENT		UPPER LIMB : ○ RIGHT ○ LEFT																			
SHOULDER POSITIONS AND MOVEMENTS	 <p>[A1] MOVEMENTS IN EXTREME ARTICULAR RANGE: THEY TAKE : [4] 1/3, [8] 2/3, [12] 3/3 of cycle/task time</p> <p>[A2] LACK OF VARIATIONS: performs work gestures of the same type involving the shoulder for at least 50% of the cycle/task time: [4]</p> <p>[A3] KEEPS THE ARM RAISED (unsupported) by an angle more than 60° or in extension, for : [4] 1/3, [8] 2/3, [12] 3/3 of cycle/task time.</p> <p>[A4] KEEPS THE ARM RAISED (unsupported) continuously more than 20° or in extension for at least 50% of cycle task/time: [4]</p>	RISK SCORE IN CYCLE [1 6]																			
ELBOW MOVEMENTS	 <p>[B1] MOVEMENTS IN EXTREME ARTICULAR RANGE: THEY TAKE: [4] 1/3, [8] 2/3, [12] 3/3 supination } of cycle/task time [2] 1/3, [4] 2/3, [6] 3/3 pronation } [2] 1/3, [4] 2/3, [6] 3/3 flexion }</p> <p>[B2] LACK OF VARIATION: Performs work actions of the same type involving the elbow for at least 50% of the cycle: [4]</p>	[0 8]																			
WRIST POSITIONS AND MOVEMENTS	 <p>[C1] MOVEMENTS IN EXTREME ARTICULAR RANGE: THEY TAKE: [2] 1/3, [4] 2/3, [6] 3/3 r/u deviation } of cycle/task time [4] 1/3, [8] 2/3, [12] 3/3 extension } [2] 1/3, [4] 2/3, [6] 3/3 flexion }</p> <p>[C2] LACK OF VARIATION: Performs work actions of the same type involving the wrist for at least 50% of the cycle/task time: [4]</p> <p>[C3] STATIC POSTURES IN EXTREME ARTICULAR RANGE: THEY TAKE : [2] 1/3, [4] 2/3, [6] 3/3 of cycle/task time.</p> <p>[C4] KEEPS THE WRIST FLEXED OR EXTENDED OR DEVIATED Laterally (ulna or radius) continuously for at least 50% of cycle/task time: [4]</p>	[0 4]																			
TYPE OF GRIP AND FINGER MOVEMENTS	<p>[D1] TIME OF THE GRIP AND FINGER POSITION:</p> <table border="0"> <tr> <td>TIGHT GRIP (1.5 CM)</td> <td>[2] 1/3, [4] 2/3, [6] 3/3</td> <td rowspan="6">} of cycle/task time</td> </tr> <tr> <td>PINCH</td> <td>[3] 1/3, [6] 2/3, [9] 3/3</td> </tr> <tr> <td>PALMAR GRIP</td> <td>[4] 1/3, [8] 2/3, [12] 3/3</td> </tr> <tr> <td>HOOKE GRIP</td> <td>[4] 1/3, [8] 2/3, [12] 3/3</td> </tr> <tr> <td>KEYING</td> <td>[4] 1/3, [8] 2/3, [12] 3/3</td> </tr> <tr> <td>.....</td> <td>[1] 1/3, [2] 2/3, [3] 3/3</td> </tr> <tr> <td>.....</td> <td>[1] 1/3, [2] 2/3, [3] 3/3</td> <td></td> </tr> <tr> <td>.....</td> <td>[1] 1/3, [2] 2/3, [3] 3/3</td> <td></td> </tr> </table> <p>LACK OF VARIATIONS:</p> <p>[D2] performs work actions of the same type involving the same finger(s) for at least 50% of the cycle: [4]</p> <p>[D3] holds an object in a pinch or palmar (or hook) grip continuously for at least 50% of the cycle: [4]</p>	TIGHT GRIP (1.5 CM)	[2] 1/3, [4] 2/3, [6] 3/3	} of cycle/task time	PINCH	[3] 1/3, [6] 2/3, [9] 3/3	PALMAR GRIP	[4] 1/3, [8] 2/3, [12] 3/3	HOOKE GRIP	[4] 1/3, [8] 2/3, [12] 3/3	KEYING	[4] 1/3, [8] 2/3, [12] 3/3	[1] 1/3, [2] 2/3, [3] 3/3	[1] 1/3, [2] 2/3, [3] 3/3		[1] 1/3, [2] 2/3, [3] 3/3		[1 3]
TIGHT GRIP (1.5 CM)	[2] 1/3, [4] 2/3, [6] 3/3	} of cycle/task time																			
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.....	[1] 1/3, [2] 2/3, [3] 3/3																				
.....	[1] 1/3, [2] 2/3, [3] 3/3																				

positions are summed up considering time pattern during the cycle.

As for the elbow, the operator carries out pronation movements (and return from pronation) >60° for two-thirds of cycle time.

Under the elbow B1, enter two-thirds of cycle time for pronation movement (score 4), and in B2 enter "4" for movement stereotypy.

The elbow has an overall score of 8.

The wrist joint does light flexion (and return from the flexion) movements, but for gestures of the same type, and for two-thirds of cycle time. Under C2 fill in 4.

The overall score for the wrist is 4.

The hand is involved in concurrent precision grip (PINCH).

These gestures are always the same, and last for the whole of the cycle. Under D1 sign 3/3 (score 9); under D3 sign the box 4; the overall score the hand is 13.

When the cycle time is extremely short (e.g. shorter than 6 sec.), the stereotypy of the technical actions is always present.

Appendix B: An example for calculating lack of recovery period exposure scores (Colombini 1998)

A still empirical but effective way of performing such analysis is by examining individually the hours that make up the shift; for

each hour it is necessary to verify whether repetitive tasks are carried out and whether there are adequate recovery periods (Colombini 1998).

According to the presence/absence of adequate recovery periods within each hour of the repetitive work under examination, each hour is considered as being either "risk-free", or "at risk" if there is a lack of adequate recovery periods.

The overall risk related to lack of recovery periods could be determined by the total number of hours of the shift in which recovery is insufficient.

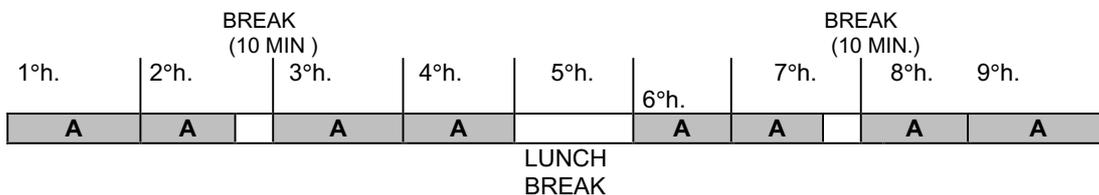
A possible example to obtain a risk score for lack of recovery periods is shown in example 5 (Figure 4).

The risk due to a lack of recovery periods is classified with a score of 4. This expresses the number of hours in the shift in which the recovery is insufficient. In an eight-hour shift, with a lunch break but with no other pauses at all, the score will be 6; in fact, the hour of work followed by the lunch break, just as the last hour before the end of the shift, can be considered as risk-free, because they are followed by adequate recovery periods.

Appendix C: Recommended force limits for machinery operator (PrEN 1005-3 1996)

- Define relevant actions and force directions.
- Obtain distribution parameters (average and standard deviation) of the maximal isometric force for the relevant action in the general adult healthy European population.
- Decide if the machinery is intended for professional or domestic use.

In a working situation where a single repetitive task is carried out (task A), and where pauses are distributed as follows:



the following scheme (protocol) should be adopted:

1st HOUR	= 60 min. TASK (no rec.)	= RISK 1
2nd HOUR	= 50 min. TASK: 10 REC.	= RISK 0
3rd HOUR	= 60 min. TASK (no rec.)	= RISK 1
4th HOUR	= 60 min. TASK	
5th HOUR	= 60 min. REC.	= RISK 0
6th HOUR	= 60 min. TASK (no rec.)	= RISK 1
7th HOUR	= 50 min. TASK: 10 REC.	= RISK 0
8th HOUR	= 50 min. TASK (no rec.)	= RISK 1
9th HOUR	= 60 min. TASK + RECOVERY	= RISK 0
	END OF SHIFT	

Figure 4. Protocol for work/rest schedule on repetitive tasks.

- Determine F_b , i.e. the 15th force percentile for professional use or the 1st percentile for domestic use.

Appendix D 1: Evaluation of working postures (ISO/DIS 11226 1998)

The holding time for upper arm elevation is evaluated using Figure 5.

It is recommended to provide adequate recovery time following the holding time for a certain upper arm elevation.

Appendix D 2: Evaluation of working postures in relation to machinery (CEN prEN 1005-4 1997)

Upper arm elevation

Step 1: refer to figure and table below

Step 2:

- (a) Acceptable if there is full arm support; if there is no full arm support, acceptability depends on duration of the posture and period of recovery.
- (b) Not acceptable if the machine may be used for long durations.
- (c) Not acceptable if frequency ≥ 10 / minute and/or if the machine may be used for long durations.

The holding time for upper arm elevation is evaluated using the table below.

HOLDING TIME	ACCEPTABLE	NOT RECOMMENDED
> maximum acceptable holding time*		X
\leq maximum acceptable holding time*	X	

- Taken from the figure below.

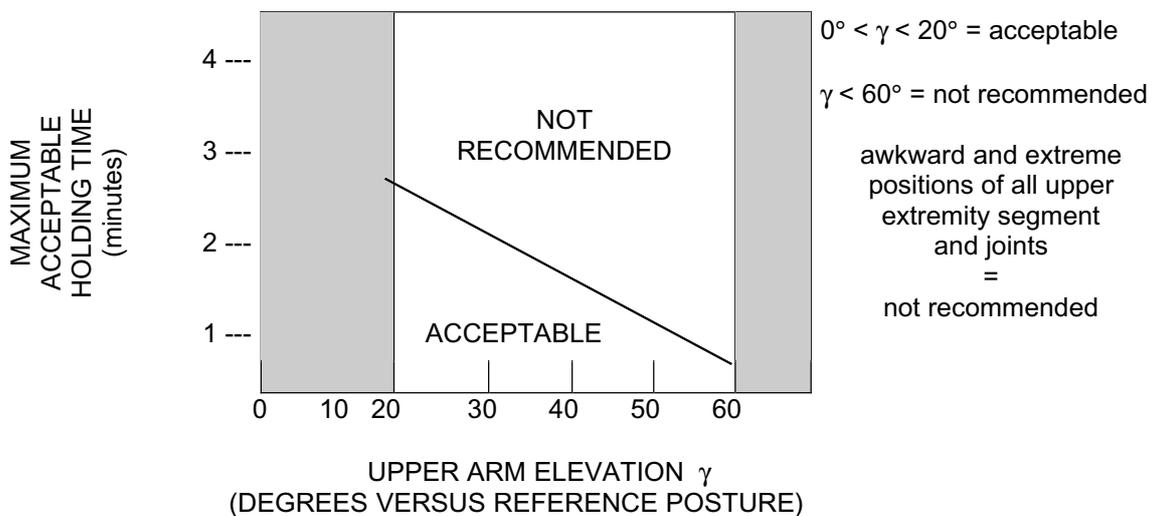
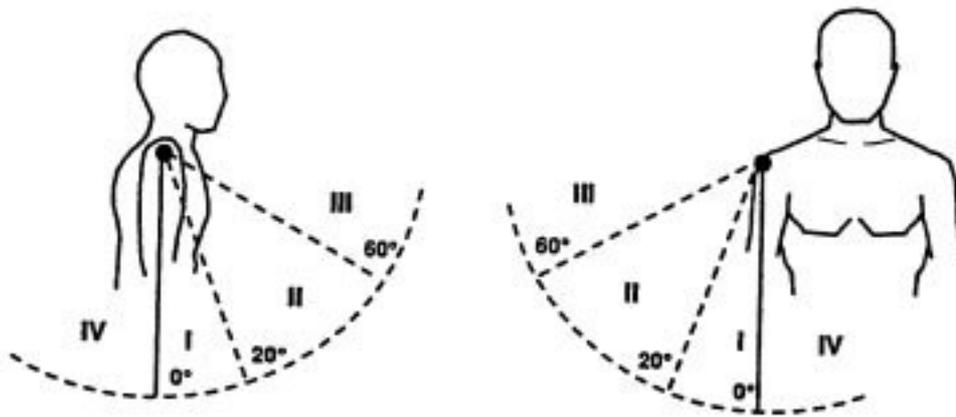


Figure 5. Maximum acceptable holding time.



Upper arm elevation

Evaluation of upper arm elevation

	Static posture	Movement	
		low frequency (<2/minute)	high frequency (≥2/minute)
I*	acceptable	ACCEPTABLE	acceptable
II	conditionally acceptable (step 2A)	acceptable	conditionally acceptable (step 2C)
III	not acceptable	conditionally acceptable (step 2B)	not acceptable
IV	not acceptable	conditionally acceptable (step 2B)	not acceptable

Static posture and high frequency movements (≥ 2 / minute), awkward and extreme positions of all upper extremity segments and joints = not acceptable

* It is recommended to strive for working postures with the upper arms hanging down.

Figure 6.