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Assessment of exposure to repetitive upper limb movement: an IEA consensus document

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This article outlines a consensus document on repetitive movement exposure assessment developed by the Technical Committee on Musculoskeletal Disorders of the International Ergonomics Association (IEA). The document is also endorsed by the International Commission on Occupational Health (ICOH). The main authors of the document are D. Colombini (co-ordinator) and E. Occhipinti (EPM), Italy; N. Delleman (TNO), Netherlands; N. Fallentin (NIOH), Denmark; A. Kilbom (National Institute for Working Life), Sweden and A. Grieco (University of Milan), Italy who also chairs the IEA Technical Committee.

The full document has yet to be submitted for peer review, but is extensively summarised here. More details on methods of application can be found in a special issue of *Ergonomics* (Colombini D., Occhipinti E. (1998), vol. 41, n° 9).

Aim

The consensus document sets out to lay down definitions, criteria and procedures for describing and, where possible, assessing work conditions that may physically overload the different structures and segments of the upper limbs. It is intended to provide all WSMD prevention practitioners with methods and procedures easily applicable in the workplace, based on observation procedures where possible.

The proposed methods are based as far as possible on knowledge and data gleaned from scientific literature: conflicts and failings are addressed by reference to international standards or pre-standards, on the basis of the researchers' experience and common sense.

General model of assessment and definitions

The description and general model of assessment for all exposed workers in a given situation aims to evaluate four key collective risk factors: repetitiveness, high force, awkward postures and movements, lack of proper recovery periods. These factors are assessed as a function of time (chiefly their respective duration). Other factors are also to be considered. These we have classed as "additional factors".

Each identified risk factor is properly described and classified. This allows special requirements and preliminary preventive action for each factor to be identified, and enables all the factors contributing to overall "exposure" to be accommodated within a general, mutually integrated framework. From this viewpoint, it may be useful to classify results quantitatively or by category. To this end, the definitions reported in Table 1 p. 23 are important. The suggested procedure for assessing the risk is the multistage one listed below:

- pinpoint the typical tasks of a job, including those which take place in equal repetitive cycles for significant lengths of time;
- find the sequence of technical actions in the representative cycles of each task;
- describe and classify the risk factors within each cycle (repetitiveness, force, posture, additional factors);
- reassemble the data on the cycles in each task for the whole work shift, taking into consideration the duration and sequences of the different tasks and recovery periods;
- produce a brief, structured assessment of the risk factors for the job as a whole.

Organisational analysis

Organisational analysis should precede the analysis of the four main risk factors and additional factors. It is essential to focus on the real **duration** of **repetitive tasks**, and the existence and distribution of **recovery periods**. The organised work shift may consist of one or more work tasks. In turn, each task may be characterised by cycles or other types of execution. If the task is characterised by cycles of mechanical actions, it will be defined as a **repetitive task**. If it is characterised by checking operations (examination, inspection) not involving movements or awkward mechanical actions, it will be defined as an upper limb recovery period.

Tasks with non-repetitive mechanical actions are defined as **non-repetitive tasks** (but not "recovery

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Table 1

Definitions of main recurring terms used in exposure assessment

ORGANISED WORK: The organised grouping of work activities that are carried out within a single work shift; it may consist of one or more tasks.

TASK: Specific work activity designed to achieve a specific operational result.

Tasks are classified as:
- *Repetitive tasks:* characterised by repeated cycles with mechanical actions.
- *Non-repetitive tasks:* characterised by the presence of non-cyclical mechanical actions.

CYCLE: A sequence of technical, mainly mechanical, actions, continually repeated in the same way.

TECHNICAL ACTION (mechanical): An action that implies a mechanical activity; not necessarily to be identified with a single joint movement, but rather with the complex movements of one or more body regions enabling 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 unit (actions per minute). High frequency is the related risk factor.

FORCE: The force exerted required by the worker to execute the technical actions.

POSTURE: The set of postures and movements used by each main joint of the upper limb to execute the sequence of technical actions that characterise a cycle.

Awkward posture: hazardous postures for the main upper limb joints.

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: These may be present in repetitive tasks, but not necessarily or always. Their type, intensity and duration lead to an increased level of overall exposure.

periods"). The number of cycles planned within a **repetitive task**, and the net duration of each cycle, must be counted at this point. The number of cycles often coincides with the number of pieces to be worked in each shift.

Risk factors

1. Repetitiveness - Frequency

Repetitiveness can be used to characterise tasks for assessment. For this, a repetitive task for the upper limbs can be defined as an activity of at least an unbroken hour in which the subject carries out a similar series of work cycles of relatively brief duration (a few minutes at most). Once repetitive tasks are submitted to analysis, there is the more important problem of quantifying and assessing repetitiveness.

In our proposal, repetitiveness is measured both by counting the number of technical actions performed by the upper limbs within the cycle, and by identifying, for each action, how many times (or for how long) they involved a given posture or movement of each main segment/joint of the upper limbs (see posture and movement analysis, p. 24).

Describing the technical actions often means filming the job, and reviewing it afterwards in slow motion. The company will often have records available describing and numbering the task, and timing the elements constituting successive technical actions (Time and Motion Studies).

Frequency is analysed by the following sequence:
- description of the technical actions;
- calculation of action frequency. From the work organisation study already conducted, we already know: the net repetitive task time, number of repetitive task cycles, duration of each cycle.

From the description of technical actions, we can calculate the number of actions per cycle, and hence the action frequency in a given time unit: **number of actions per minute**. We can also obtain the overall number of actions in the task(s), and consequently for the shift.

2. Force

Force more directly represents the biomechanical effort necessary to carry out a given action - or sequence of actions. 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).

Force quantification in real life contexts is a problem. Because of field applicability problems, two different methods are recommended to evaluate the use of force associated with the technical actions present in a cycle.

■ ***Dynamometers***

This procedure is recommended for actions involving the use of levers, or components of machines and objects. A dynamometer can be used to determine the force required to move a lever, or, equipped with the proper interface, to simulate the same working action by the workers involved. Even so, not all technical actions requiring the use of force can be easily determined by means of dynamometers.

To evaluate the use of force, the field results obtained must be compared against a reference working population. For this, relevant data can be found either in the literature (Rohmert *et al.*, 1994) or sourced from national or international standards institutions.

■ ***Psychophysical rating scales***

Here, the worker's subjective evaluation is used to determine the physical effort associated with the cycle technical actions. Different psychophysical scales are available in the literature; we have used the "CR10 Borg scale" for perceived exertion.

While subjective scales are not completely error-free, if correctly used they do allow researchers to evaluate the effort associated with any technical action. The reference values for evaluation are provided by the scale itself.

The procedure, when applied to all workers involved, can be used to evaluate the average score among subjects for each technical action as well as the weighted average score for all actions and the entire cycle time.

Finally, whatever the method used to describe and assess force, it is necessary to evaluate:
• the average level of force required by the whole cycle, referred to as the maximum force capability, is defined by reference groups or the group of workers involved;
• whether the cycle includes technical actions requiring the development of force beyond given levels (peak force), and if so, which and how many.

3. Posture and types of movements

There is a clear consensus in the literature as to the potential damage wrought by extreme postures and movements of each joint, from protracted postures (even if not extreme) and from specific, highly repetitive movements of the various segments. Moreover, the description of postures and movements of each upper limb segment during the technical actions of a cycle completes the description of the "repetitiveness" risk factor. The analysis of postures and movements focuses on each single upper limb segment (hand, wrist, elbow, shoulder): it aims to check 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 must assess at least:
• technical actions requiring postures or movements of a single segment beyond a critical level of angular excursion;
• technical actions involving postures and/or movements which, even within acceptable angular excursion, are maintained or repeated in the same way;
• the duration expressed as a fraction of cycle/task time of each condition reported above.

The combination of these description factors (posture/ time) for each joint will provide the classification of posture effort for each segment considered. It must be emphasised that at this stage, it is less important to describe every posture and movement of the different upper limbs segments than to focus on those which, by typology or excursion level (as well as by duration), are static postures and/or movements involving greater effort and also requiring improvement.

For an exhaustive description of postural risk, the following operational phases must be covered:
• a separate description of postures and/or movements for each joint - shoulder, elbow, wrist, hand (type of grip and finger movements) - and type of effort (static, dynamic);
• static postures: observation of static postures close to extreme articular range during the cycle/task time; observation of static postures in the articular mid-range held for a prolonged period of time; observation of grip positions during cycle/task time;
• joint movements: presence of articular movements near the limit of the range of motion during the cycle/task time; repetitive articular movements from the same technical actions (independently of the articular range) for at least 50% of cycle time and subsequently of task time.

For practical purposes, a significant cycle should be analysed for each repetitive task. This is better achieved by videotaping. The video can then 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. Lack of recovery periods

The recovery period is a time during which one or more of the muscle groups usually involved in the work tasks are basically inactive (macro-pauses). The following may be considered as recovery periods:

• work breaks, including the lunch break;
• periods during which tasks are carried out which do not involve the usual muscle groups;
• periods within a cycle involving actions affording complete rest to the usually active muscle groups; to be classed as macro-pauses, these periods must be at least 15 unbroken seconds.

Analysis of the recovery periods is a check on their duration and distribution within the cycle, and a macroscopic examination of their presence, duration and frequency within the whole shift. With some exceptions, represented by recovery periods for actions implying protracted static contractions, the description and assessment of recovery periods should be based on:

• a description of actual task sequences involving repetitive upper limb movements, "light" non-repetitive tasks, and pauses;
• the frequency of the recovery periods with reference to the actual number of working hours per shift;
• 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 analysing recovery periods is the lack of criteria for an adequate assessment (duration, time scheduling).

In this connection, the following should be considered:

■ ***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.

It should be emphasised, however, that such data refer to effects like performance or, at best, muscular fatigue but are not fully validated as respects major health effects.

■ ***Dynamic actions***

No adequate studies are available for evaluating the optimum distribution between repetitive work time and recovery time. The absence of consolidated scientific studies on the optimal distribution of recovery periods makes it 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 suggest that:

1. work involving repetitive upper limb movements cannot be continuously sustained for over one hour without a recovery period;
2. the recovery period within an hour of repetitive work must be in the range of 10-20% of working time (about 5-10 minutes an hour). These rough indications still to be perfected, may guide description and assessment methods for recovery periods for "dynamic" upper limb work.

5. Additional risk factors

Other factors apart from those already discussed are considered to be relevant in the development of WMSDs. They are always work-related, and must be taken into consideration when assessing exposure. They have been described as additional, not because they are of secondary importance, but rather, because each may be either present or absent in the various occupational contexts. For a factor to be considered, it must have an association with WMSD effects, as well as having a collective impact (that is on all or significant groups of the exposed subjects) rather than an individual impact (that is on single subjects). The additional risk factors may be mechanical, environmental or organisational. The list of factors cited here (table 2) is only indicative

Table 2
List of possible additional risk factors (indicative list)

MECHANICAL RISKS

- Hand-arm vibrations
- Extreme precision in positioning objects
- Localised 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 RISKS

- Exposure to cold
- Exposure to heat

ORGANISATIONAL RISKS

- Machine-paced task
- Incentive payment
- Routine overtime
- Working to tight deadlines
- Sudden peaks of high workload
- Lack of training

and not exhaustive: each operator will decide on what single factors are relevant to assess overall exposure in the circumstances.

Mechanical and environmental factors can be described and assessed according to the corresponding time pattern (frequency, duration). Organisational factors can be described according to category classifications (at least as present/ absent).

Overall exposure assessment

An overall exposure assessment must account for different risk factors, individually described and classified. While the simplest and most elementary prevention actions can be implemented after proper analysis of each risk factor, more comprehensive prevention strategies must be based on an assessment of overall exposure as determined by the different combination of the risk factors considered. In this regard, the literature already offers data and convincing hypotheses on the interrelation between some of those factors. This notwithstanding, it must be said that in the present state of knowledge there is still insufficient data to outline an accurate, 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.

Though accounting for this, we must stress the need for even partially empirical models for a concise assessment of overall exposure to the risk factors considered. Methods and procedures for determining concise exposure scores already exist in the literature (Keyserling *et al.*, 1993; Schneider, 1995; Mc Atamney *et al.*, 1993; Moore and Garg, 1995). A concise index has been recently proposed (Occhipinti, 1998) providing a classification of the risk factors considered here (repetitiveness, force, posture, lack of recovery periods and additional risk factors). This index model has been the subject 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 on from the exposure assessment process.

Mindful that the data supporting the above overall exposure assessment models are still wanting and often empirical, it is recommended that, if used, they should be approached "critically" in studies for preventive action and/or for the active health surveillance of workers. In this regard and with these goals, the following aspects should be considered:

- the exposure indices proposed at present have a methodological value, showing the concept of the integrated evaluation of risk factors;
- such indices have also a practical value: even if they do not provide an absolute statement of the exposure (and hence WMSD risk), they do at least permit a ranking of the exposure level derived mainly from the combination of the different factors in the different work situations. This allows action and intervention to be prioritised. At present, an index can only be used in combination with health status monitoring (complaints, disorders) of the workers involved, in order to determine whether the proper action and intervention have been chosen;
- the exposure indices proposed here are not intended as standards or reference values to distinguish safe or hazardous conditions: this should be made clear to potential users;
- the exposure indices proposed here, or in the future, need to be validated by laboratory studies, as well as by epidemiological studies (exposure/effect). ■

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