Exposure Assessment of Upper Limb Repetitive Movements: Ergonomic Principles for Prevention

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1 INTRODUCTION

When both the exposure assessment and the study of workrelated musculoskeletal diseases have revealed a significant risk associated with repetitive and/or strenuous movements of the upper limbs in various work environments, the need arises to implement specific measures aimed at redesigning jobs and procedures. Their efficacy depends on three types of coordinated and virtually simultaneous actions being carried out: structural modifications, organizational changes, and personnel training.

Although the structural measures are almost universally accepted and widely recommended, actions involving organizational changes do not always meet with unanimous consent, and the scientific literature does not provide concrete examples. Instead it merely supplies general and routine advice, such as reduce excessively high job frequencies, or introduce adequate breaks or job alternatives. This article aims to provide some concrete guidelines for redesigning jobs and preventing disorders caused by repetitive movements of the upper limbs.

2 STRUCTURAL MEASURES

Structural measures primarily concern ways of finding an optimal arrangement for the workplace, furnishings and the overall layout of the environment, and ergonomic work tools. In general, these measures aim to improve aspects related to awkward posture and movements, localized compressions of the anatomical structures of the upper limbs, and the use of excessive force. Structural measures thus seek to reduce the consequences of the most important risk factors — posture and force — and of any other risk factors.

2.1 Criteria for Limiting the Risk Associated with Posture

As far as posture is concerned, the main principle to be kept in mind is to avoid prolonged movements or positions that force the joints to exceed 50% of their maximum range. Redesigning the job means allowing the worker to maintain posture or joint motion below 50% of the maximum specific range for each joint. In order to ensure the correct position of the upper limbs, it is essential to correctly design the workplace. Three aspects need to be emphasized:

- Suitable workbench height when standing or sitting;
- Suitable chair height for seated positions;
- Suitable operating areas for the upper limbs;

Different standards, ergonomic manuals, and checklists supply the main design principles for preventing awkward posture and/ or movements harmful to the shoulder, elbow, wrist, hand, and fingers (Eastman Kodak Company 1983).

2.2 Criteria for Limiting the Risk Associated with Force

The main principle is to avoid overstraining the muscles; when the upper limbs have adopted an awkward posture, especially the wrist and hand, the ability of the muscles in the strained segment to apply force is drastically reduced. The force that can be developed in pinching movements is only 25% of the total grip force of the hand; moreover, grip force gradually diminishes as the wrist departs from the anatomical position. In order to intrinsically reduce excessive strain, the following recommendation can be made:

- Avoid even occasional contractions exceeding 50–60% of the maximum individual capacity.
- On average, no muscle–tendon unit should be exerted for more than 15% of its maximum capacity in any given shift.

The lower the degree of muscular exertion, the longer the permitted duration of the exertion. And the lower the degree of muscular exertion, the greater the number of movements that can be made in performing a repetitive task with consequent positive repercussions on productivity levels.

Generally speaking, it is possible to reduce the need to use force by using power-driven tools, by using mechanical grippers and holders (more efficient levers in positions better suited to the stronger muscle-tendon units), and by automating the entire action. Instruments and tools must meet a series of requirements in order to limit the risks associated with posture and force, hence reducing the risk of accidents in the workplace. An ergonomic instrument or tool may be defined by what it avoids:

- Avoid having to deviate the wrist by more than 50% of its normal range.
- Avoid repetitive movements using a single finger.
- Avoid handpieces requiring grips awkward to the development of force.
- Avoid pulling movements and striking actions.
- Avoid localized compressions.
- Avoid the transmission of mechanical vibrations.

Ergonomic instruments or tools should also be coated with a slip-proof finish, they should not conduct heat, and they should not have sharp edges, pointed tips, or potentially harmful shapes.

3 ORGANIZATIONAL MEASURES

Measures typically involving changes to the work organization become necessary when it has been ascertained that jobs feature excessively frequent technical actions and/or inadequate functional recovery periods. Here is a revealing example. In a large metalworking factory featuring assembly lines, upper limb disorders appeared to be prevalent (carpal tunnel syndrome, tendinitis, etc.), most of them attributable to repetitive tasks performed with excessive frequency and/or with lack of proper recovery periods.

On the advice of the local health authority, the company asked to carry out a detailed risk analysis in order to develop options for redesigning workstations more ergonomically. The exposure assessment identified the following problem areas:

- High frequency actions (38–40 technical actions per minute).
- In general, minimal use of force; in almost all cases the company quickly found specific solutions for bringing the use of force to within acceptable limits.
- Posture seldom extreme and therefore easily corrected by making some structural modifications to the workstation.
- Recovery periods taken primarily for physiological reasons rather than for alternating jobs.

The daily schedule included two morning breaks (10 min and 15 min), a 30 min lunch break, and one 10 min afternoon break. One simple change involved optimizing the recovery periods. The total duration of the physiological breaks was already sufficient; by simply redistributing the breaks, it was possible to ensure adequate recovery periods without altering their overall duration. The company redistributed the physiological breaks (35 min = 10 min + 15 min + 10 min) so as to obtain four breaks (two in the morning and two in the afternoon).

In this case the last problem that needed solving was the high frequency of the technical actions. The first and most obvious intervention was to reduce the pace of the task, identifying methods for reducing the number of technical actions required to complete a job cycle but without compromising output. In other words, this meant optimizing — in terms of quality and quantity — the technical actions needed to complete the cycle characterizing the task.

Through valuable cooperation between the ergonomist and the production engineer, it was possible to use the fundamental experience of the engineer not to enhance productivity, but to improve working conditions and thus the health of the workers. By careful filming and critical analysis, each task was revised several times to make it better. In order to reduce the number of actions contained in a cycle, the following procedure was used.

3.1 Phase 1: Analysis of Useless Technical Actions

During phase 1 it is decided whether all the observed technical actions are strictly necessary. It is thus possible to single out useless actions performed by the operator and even actions which could be designed out of the task. In practice this has three aspects:

1. Detecting any useless actions added by the operator. For example, when assembling a piece, the operator occasionally strikes the piece more often or screws the piece more tightly than required: two strokes might be necessary, but the operator actually performs 4, 5, or 6 strokes. In this case the operator must be trained to perform no more than the useful actions actually required to perform the task.
2. Detecting whether any actions added by the operator are entirely arbitrary or in fact conceal a manual flaw. For example, a faulty pin does not fit snugly so the operator needs to strike it several times to force it into the correct position.
3. Detecting obsolete actions. In the course of time, assembly lines may undergo small changes to the machinery or to the product, rendering certain actions obsolete. Therefore it is extremely useful to check the way operators perform their tasks whenever machinery or products are modified.

3.2 Phase 2: Analysis of Upper Limb Use when Performing Technical Actions

Once all useless actions have been eliminated, the next step is to optimize the distribution of the various actions between the two upper limbs. Workers often tend to favor their dominant limb. Simple low precision actions (e.g. picking up workpieces and placing them on the machining line) may be performed equally by both limbs, thus reducing the frequency with which the dominant limb is used.

3.3 Phase 3: Analysis of Identical Technical Actions

Phase 3 determines whether workers are repeating identical actions for a significant portion of the job cycle. Repetition of identical technical actions can often be avoided by introducing a specific mechanical device. One of the following solutions may be adopted when identical technical actions have been identified but no suitable tools can be introduced and when simultaneously the action frequency considerably increases the total frequency:

- Eliminate the specific manufacturing step altogether by having the part arrive preassembled elsewhere; this is a simple solution but make sure it does not lead to another high risk job being created.
- Introduce a semiautomatic step to replace the technical actions; this is a high cost solution.
- Reexamine the phase scientifically to find alternative solutions capable of fully bypassing the specific action sequence; this hi-tech solution often improves the product.

3.4 Phase 4: Analysis of Auxiliary Actions

Check whether any auxiliary actions are performed in passing from one cycle to the next. It is generally useful to have the conveyor belt and operating areas cross each other in such a way as to avoid the worker having to pick up and replace pieces. To minimize handling, it is equally helpful for the piece to reach the worker facing the right way.

3.5 Phase 5: When Jobs Need to Be Split

Despite carefully reviewing actions, sometimes their frequency remains excessively high (even 60 actions per minute). Then the jobs need to be split. Remember that, with no other risk factors involved, a frequency of 30 actions per minute is taken as a reference “acceptable” frequency. Several workstations still feature frequency levels higher than this threshold. Then it is necessary to at least introduce hourly job switches, so the workers performing jobs that might still potentially overload the upper limbs can alternate with less strenuous jobs.

Since the same manufacturing line features workstations with relatively low action frequencies, it will not be difficult to arrange for workers to switch jobs regularly. In essence, job switching is very useful for reducing the risk of exposure to the frequency factor; it has two principal advantages:

- It allows workers to alternate between workstations where the frequency risk is low and workstations where the frequency risk is high.
- It allows workers to alternate between workstations in which the use of the upper limb changes (between left and right).

Besides alternating jobs to prevent disorders due to repetitive movements, adequate recovery periods are critically important in their own right. A suggested ratio of work periods to recovery periods is 5:1 within each hour of repetitive work. Often factories schedule long enough recovery periods (i.e. actual breaks and/or nonrepetitive tasks) but they are poorly distributed throughout the duration of the repetitive task. Here are some ways to improve them:

- Optimize the distribution of official breaks: it is preferable to shorten each individual break, but to increase their frequency.
- Arrange, if possible, for rest periods to be scheduled at the end of an hour of repetitive work.
- Avoid the scheduling of rest periods too close to meal breaks and shift ends; this allows meal breaks to be used as recovery periods.
- Rotate workers in nonrepetitive tasks, so as to obtain an optimal distribution of repetitive and nonrepetitive tasks, thus ensuring a good ratio of work periods to recovery periods.

4 TRAINING PROGRAMS

4.1 Training for Factory Workers

Workers must be informed of the risks and the kinds of disorder associated with repetitive tasks, in order to justify and motivate the need for these tasks to be performed correctly and in the proper order. Workers must therefore be suitably trained to follow these rules:

- Perform tasks in the required order.
- Use both limbs whenever possible.
- Avoid adding useless actions.
- Grip objects correctly.
- Notify the supervisor whenever new actions need to be performed.
- Contact the health officer as soon as early warning signals are noticed.

4.2 Training for Production Engineers and Supervisors

Training engineers and supervisors is based on a clear understanding of the specific risks and injuries as well as the medicolegal implications associated with occupational diseases. It is necessary for engineers and, above all, supervisors, to organize periodic meetings with workers in order to gather information on any practical problems emerging from the various tasks. Their prompt detection and elimination will prevent unnecessary damage to workers' health, and often leads to a better product. Thus the production engineer is a key figure in the training process, receiving training and insight from expert consultants and providing practical training for the workers.The production engineer has the following responsibilities:

- Suitably design how a task must be performed, above all optimizing the technical actions in terms of human health, not just productivity.
- Teach workers how to perform tasks correctly.
- Periodically check that tasks are being performed correctly.
- Periodically talk with workers about the possible onset of problems while performing tasks.
- Check that technological innovations do not cause increased risk factors.
- Attend to new workers and ensure they are given proper training for their tasks, especially complex tasks.

4.3 Training for Management

Managers need to be involved in the training process. Training must be carried out by experts. Managers must be able to provide trainers with a thorough picture of the risk factors present in the work cycle, as well as possible strategies to ensure they are minimized and effectively managed.

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