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Ergonomics in the continuous development of production systems

A COPE-workshop on methods for collecting and analyzing mechanical exposure data

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Preface

The R&D program COPE was initiated in 1996 by four Swedish research teams in Stockholm, Göteborg and Lund. COPE stands for ’Co-operative for Optimization of industrial production systems regarding Productivity and Ergonomics’. A major aim of the program is to develop a ’tool-box’ for company stakeholders, containing methods and procedures for integrating ergonomics into the continuous development of industrial production systems.

A workshop was arranged on March 8th 1999 in Stockholm, with the purpose of developing tools for assessment of mechanical exposures (physical work load). The workshop was attended by 27 Nordic participants, and seven experts were specifically invited to give presentations as a basis for discussion of the following five issues:

- Who are the users of the tool-box and what are their needs?
- Which are the appropriate measures of exposure from a scientific viewpoint?
- Do any available exposure methods candidate for the tool-box?
- Which exposure methods should be further developed towards integration in the tool-box?
- How could these methods be transformed into attractive tools for the tool-box?

The present publication contains written presentations of the experts, as well as an introductory chapter presenting the background of the workshop, a summary of the plenary discussion, and the effects of the workshop on R&D in COPE. We hope that the publication will stimulate further development of tools supporting an integrated technical and ergonomic analysis of new production systems.

Malmö / Solna, April 2000

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Contents

Methods for collecting and analysing data on mechanical exposure in developing production systems. A COPE-workshop

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COPE - R&D merging productivity and ergonomics

A R&D program named COPE was initiated in 1996 by four Swedish research teams. COPE stands for 'Co-operative for Optimization of industrial production systems regarding Productivity and Ergonomics', and the involved institutions are the National Institute for Working Life, Stockholm; the Department of Transportation and Logistics, Chalmers University of Technology, Göteborg; Lindholmen Development, Göteborg; and the Department of Occupational and Environmental Medicine at the University Hospital, Lund. Thus, several research disciplines are represented in COPE: physiology, ergonomics, psychology, medicine, and engineering. COPE was presented at a general level in a recent paper (Winkel et al. 1999). COPE is or has been involved in studies in cooperation with the following companies: Volvo KSO in Göteborg (car manufacturing), Autonova in Uddevalla (car manufacturing), Volvo Busses in Borås (bus manufacturing), Tarkett in Hanaskog (floor manufacturing), Berifors in Örebro (electronics assembly), and Ericsson Components in Söderhamn (electronics assembly).

COPE focuses on musculoskeletal disorders in manufacturing production systems. The approach of COPE is based on the view that sustainable ergonomic interventions against these disorders are best achieved by providing company stakeholders with tools for integrating ergonomics in their on-going system development. This view is supported by scientific reviews revealing that expert-driven modifications of isolated elements in a running system rarely lead to long-lasting positive effects (Westgaard and Winkel 1997, Winkel and Westgaard 1996). Decisions with profound ergonomic impact are instead made by, e.g., managers and engineers when establishing the basic production model, product variants, automatization level, product flow arrangements, manning, allocation of tasks among the workforce, etc. (figure 1). These decisions, in turn, reflect conditions in the company as well as in the surrounding society (figure 1). A major hypothesis in the COPE approach is that a weighing between ergonomic and engineering considerations while production is planned may lead to solutions which are effective in both aspects.

COPE conducts R&D in companies showing a pronounced initiative in the co-operation with the COPE researchers. The R&D is intended to generate both generalizable data (i.e. Research) and results directly applicable in the investigated companies (i.e. Development). COPE engages in several projects within three areas: (1) development of methods to describe, quantify and evaluate production systems regarding ergonomics and production engineering, (2) application of these methods to explore relationships between ergonomic and production engineering factors in production systems, (3) implementation of this knowledge in developing production systems.

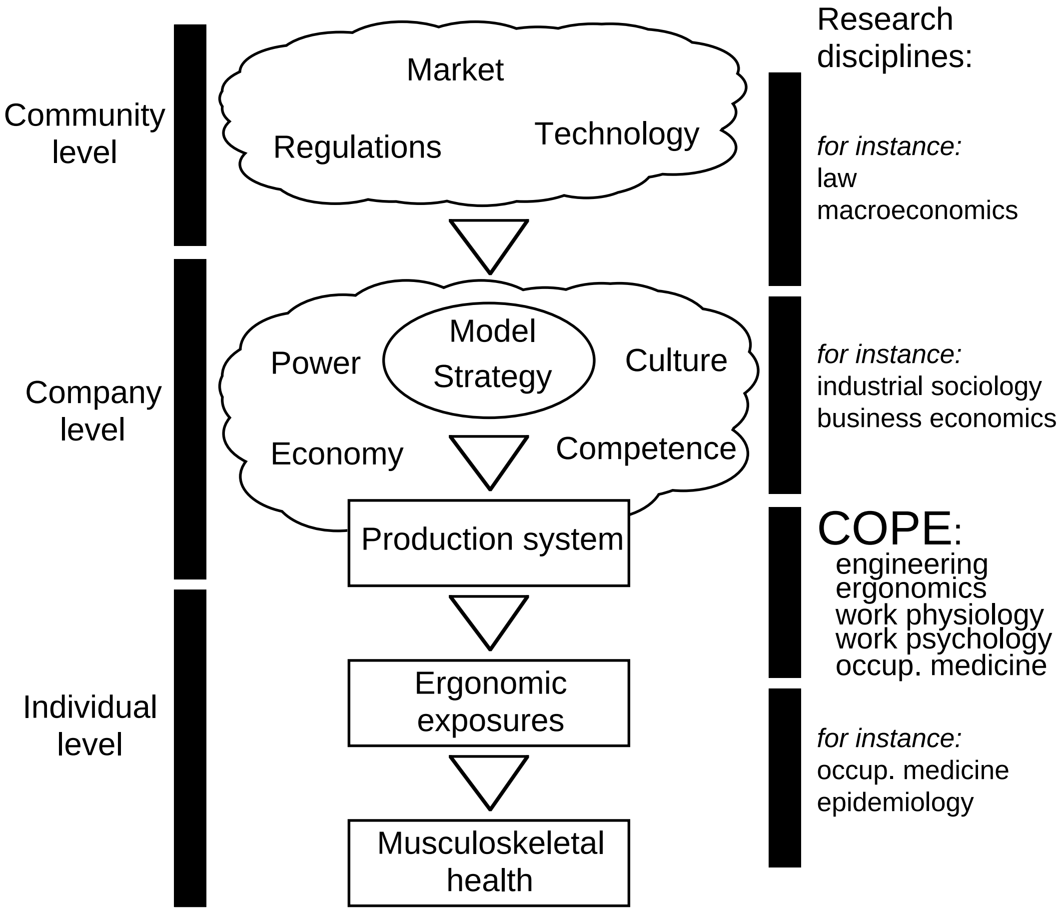

Figure 1. Ergonomic exposures and musculoskeletal health of workers are influenced by a multitude of factors at the community, company and individual levels. COPE emphasizes the links between production systems and ergonomic exposures in a multidisciplinary approach.

The *tool-box* approach

A major emphasis in COPE is put on the development of techniques which will enable practitioners in a company to perform an integrated technical and ergonomic analysis of alternative designs of a new production system, without having to engage external experts. These techniques are to be collected in a *tool-box* addressing different target groups with a significant influence on production, e.g. operators, engineers, occupational health personnel, and management. The tool-box is intended to contain methods and guidelines for three purposes: survey of running systems, prediction of performance in planned systems, and design of participatory processes. The tool-box is still under development and will be so for a long period of time.

One important focus of the tool-box is collection and interpretation of data on mechanical exposure (physical work load, Winkel and Mathiassen 1994). An abundance of mechanical exposure assessment methods may be found in the literature (Hansson and Mikkelsen 1997, Li and Buckle 1999, van der Beek and Frings-Dresen 1998), but most require a considerable specialized expertise of the user, and few can be used as an integrated part of the development of new production systems.

In order to meet the general scope of the tool-box, an exposure method should have a number of properties: compatibility with methods for collecting and analysing production engineering data, ability to operate at a work task level, reliability when used by trained practitioners, and easiness of use, e.g. through extended automatization. Evidently, the exposure methods of the tool-box must, in addition to these specific characteristics, obey general requirements of being efficient and relevant, i.e. able to predict risks for musculoskeletal orders at a reasonable cost. Some demands may be conflicting, as for instance easiness of use versus precision and relevance, or high exposure informative value versus integrability with technical analysis.

The present workshop

The present workshop was arranged as part of the process within COPE of selecting and developing mechanical exposure assessment methods for the tool-box. The arrangement took place on March 8th 1999 at the National Institute for Working Life in Solna. Seven Nordic experts were specifically invited to give presentations as a basis for discussion. The workshop was attended by, in all, 27 participants representing research institutions and official authorities (listed at the rear of this chapter). Five major questions in a logical order of succession were identified by the organizers prior to the workshop, and the Nordic experts were asked to give presentations related to one or more of these issues:

- Who are the users of the tool-box and what are their needs?
- Which are the appropriate measures of exposure from a scientific viewpoint?
- Do any available exposure methods candidate for the tool-box?

• Which exposure methods should be further developed towards integration in the tool-box?
• How could these methods be transformed into attractive tools for the tool-box?

At the workshop, the experts' presentations - all but one appearing in a written form in the present report - initiated a lively plenary discussion summarized below. References in *italics* refer to the written contributions, while those in plain text indicate viewpoints advanced orally during the discussion.

Who are the intended users of the tool-box and what are their needs?

Several experts emphasized that different tools are needed for different target groups in the company. Thus *Hägg* distinguished between ergonomically trained health care professionals, and other staff members, e.g. management and engineers. The former group may have "humanistic" motives for engaging in ergonomic interventions, while the latter require incentives based on analyses of cost and quality. Appropriate tools for non-professionals could, for instance, be models for linking ergonomics with core values in production (management), and guidelines on hazardous postures and forces (engineers). Only health care professionals may be expected to use (simple) direct measurement tools. *Takala* made a similar distinction between stakeholders responsible for the design of new work, and ergonomic consultants involved in corrective actions. *Kilbom* also emphasized the role of the occupational health and safety staff, and advocated very simple exposure assessment methods even for this group. *Hansson*, on the other hand, stated that even engineers may be a target group for direct methods requiring technical equipment. *Westgaard* questioned that quantitative methods were needed at all.

In the plenary discussion, Kilbom pointed out that trade-specific tool-boxes should be aimed at, rather than general ones. Winkel commented that the tool-box initiative so far in COPE focuses on industrial enterprises, and thus precludes e.g. private contractors and temporary agencies. Kadefors emphasized the need for tools adapted to the currently very high turn-over rate of industrial production systems, necessitated by constantly changing global market conditions.

Which are the appropriate measures of exposure from a scientific viewpoint?

Hansson implicitly advocated the use of variables related to muscle activity and movement patterns, such as electromyography from muscles at risk, and angle recordings from exposed joints. *Kilbom* believed that repetitiveness, force and posture are established risk factors for musculoskeletal disorders, but that their measurement introduces a delicate trade-off between accuracy and simplicity. In the following discussion, Westgaard tentatively suggested that peak loads, long durations of exposure at low levels, extreme postures, and time pressure were important expressions of exposure. Kilbom called for a measure of distributions of tasks across working days.

Christensen and *Westgaard* pointed out that valid, objective criteria for scrutinizing the acceptability of low, prolonged loads are not available to-day, and *Westgaard* even doubted that they will ever exist beyond the level of hypotheses. Both advised to use exposure methods based on expert judgement or the opinion of operators. The latter approach might be sensitive to crucial differences among individuals in susceptibility to disorders (*Westgaard*).

Kadefors supported the endeavour to utilize the expertise of the operator on his own job in exposure assessment. The need for including individual factors and psychosocial conditions among the measures of interest was even emphasized by *Hägg*. Mathiassen pointed out that indices describing the ergonomic performance and potential of the production system are urgently needed as an alternative to measures describing the conditions of individual operators (Mathiassen and Winkel 1997). Franzon's call for a measure of "autonomy" was commented by Hedén, stating that the official Swedish statute book on ergonomics emphasizes decision latitude, however without giving quantitative guidance (Swedish National Board of Occupational Safety and Health 1998).

Do any available exposure methods candidate for the tool-box?

The lines of development within COPE were reviewed by *Hansson*. Efforts have so far been directed towards questionnaire-based ratings of exposure to risk factors, identification of troublesome work situations from video-recordings, and collection and analysis of directly measured exposure variables adapted to engineering procedures. Other experts concentrated mainly on available checklist-type tools, preferentially aiming at health care professionals (*Hägg*, *Kilbom*, *Takala*). Westgaard advocated checklists as expressions of common-sense knowledge, while Mathiassen viewed them more as insufficient scientific information in disguise.

The possibility of developing international standards into simple qualitative or quantitative guidelines were mentioned by *Kilbom* and *Westgaard*. Work-place designers may be helped by computerized manikins, although the software is still under development (*Takala*). Kadefors mentioned the promising method "Ergo-SAM", linking ergonomic information to elementary work operations as defined by SAM-codes (Amprazis et al. 1999).

Which exposure methods should be further developed towards integration in the tool-box?

Hägg suggested that risk evaluation models should be integrated in available tools for exposure assessment. He mentioned an on-going development of a portable device surveilling the time pattern of muscle activity. *Christensen* discussed tools based on the exposure of tasks within the job. She concluded that exposure variables relating to technical issues (e.g. cycle time, work pace) seemed to discriminate between a number of predetermined tasks better than traditional posture variables. Mathiassen commented that a logical order of reasoning would rather be to first identify relevant exposure variables and then explore the ability of different task classification schemes to differentiate these variables; or, as an alternative, decide for a set-up of tasks believed to differ in risk, and search for marker exposure variables with a good ability to detect these differences.

Kadefors raised the possibility of developing tools for "three-dimensional" self-rating of mechanical, psychosocial and individual factors in the job. According to Hansson, direct technical recordings of exposure may get to be accessible even to trained practitioners after further development of hard- and software.

How could these methods be transformed into attractive tools for the tool-box?

The question was not specifically addressed by any of the experts. Implicitly, all agreed that tools have to be "simple". *Westgaard* even remarked that the implementation *per se* is a major challenge, and requires commitment from the company.

Effects of the Workshop on R&D in COPE

The presentations and discussions at the Workshop revealed that some simple exposure assessment instruments are available which were not previously known to COPE. These tools have been developed preferentially to be used by the occupational health service for surveillance purposes. Preliminary methods are even available which attempt to link mechanical exposure assessment to the production design process. These methods, some of them developed by COPE research groups, approach engineers, and present a potential for further development into tools predicting exposure in planned production systems. Some exposure features are commonly accepted to be risk-indicative, such as high peak loads and long uninterrupted periods at low loads, but it is not possible on basis of current knowledge to establish quantitative relationships between mechanical exposures and musculoskeletal disorders. Previous R&D in COPE has been in line with these views. Little appeared to be known of the consequences in terms of mechanical exposure of decisions taken at different stages in the production design process. Even the influence of different stakeholders in the company - operators, engineers, management, occupational health personnel - on decisions with an impact on mechanical exposure seems unclear. Thus, important basic information lacks for an optimal prioritization within COPE of target groups for the tool-box, as well as an appropriate shaping of attractive tools.

In summary, the Workshop supported the general R&D approach of COPE, and contributed significantly to the formation of COPE's R&D program in the period 2000-2003. Some examples are given below of planned R&D efforts relating directly to issues raised at the Workshop.

Widened target group: development of decision support for managers
A new target group is addressed by COPE in the development of tools for analyzing ergonomic and technical consequences of different strategic choices concerning basic production concepts and principles.

Simplified exposure assessment: ergonomic information in technical variables
Several key variables in engineering, especially for assessing time consumption and work pace, seemingly offer important information on mechanical exposure, in particular as regards duration and frequency of tasks. The ability of selected engineering measures to predict mechanical exposure will be explored within COPE. If succesful, this R&D will result in "short-cuts" for obtaining ergonomic data as an integrated part of an engineering analysis.

Measures based on subjective ratings: Translation of Swedish statutes into a questionnaire
The current Swedish Statute on ergonomics gives qualitative and, in some cases, quantitative guidance on how to survey and control different dimensions of mechanical exposure (Swedish National Board of Occupational Safety and Health 1998). COPE intends to explore the possibility of assessing and evaluating exposures according to the Statute through a questionnaire aiming at operators rather than ergonomists. This initiative is supported by the National Board.

Prediction of exposure: task-based integration of exposure information into computerized tools for simulating production
COPE emphasizes the development of methods for predicting mechanical exposure in production systems which have not yet been implemented. Commercial computerized tools are available for simulating product flows and analyzing their technical performance, and COPE aims at supplying data generated by these tools with ergonomic information. This will be possible only at a task level compatible with engineering, and COPE will conduct R&D to explore the construct and contents of a "task exposure matrix" for this purpose.

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Therése Möller
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Staffan Skerfving
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Measuring physical/mechanical work load for various task activities in production systems – methods applied in COPE

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Introduction

The aim of COPE is to develop methods for measuring and characterising the physical/mechanical load during actual work at the work sites. To avoid sub-optimisation of ergonomics, these methods should be versatile, and simultaneously reflect various potential risk factors for a number of body regions. Moreover, it is a great advantage if these methods can be linked to the work activities, since this enables an analysis of the production system regarding, not only the productivity, but also the work load for the various activities. Evaluation of work load may be based on self-assessment, observations and/or direct measurements (Winkel & Mathiassen 1994). Questionnaires (modified from Wiktorin et al. 1993) are used in COPE, both at a general level, and at work station level. For identifying strenuous postures and work activities, self-assessment from video recordings is used (Kadefors & Forsman 1997, Kadefors & Forsman submitted for publication). Observation based methods are also used in COPE, e.g. PEO (Fransson-Hall et al. 1995), and the Cube Model (Forsman et al. 1997).

Direct measurements, which is the focus of the present contribution, give objective and detailed information, and is thus of special interest for quantifying work load in COPE. Recent development in micro-mechanics, electronics and personal computers, regarding both hard- and soft-ware, has made direct measurements feasible to use for whole-day recordings in field studies (Asterland et al. 1996, Hansson et al. 1992, Hansson et al. 1996, Hansson et al. 1997). Since most methods for evaluating production systems use video recordings – e.g. the one used in COPE (Engström & Medbo 1997) – synchronisation of the measurements to these recordings is one possibility to link detailed ergonomic information to the various task activities. Such information makes it possible to calculate the total load ("ergonomic cost") required for producing a product, if the durations of the various tasks are known. Moreover, the change in load, due to interventions in a production system, may be predicted (Winkel et al. 1997, Winkel et al. 1999).

Direct measurement of physical/mechanical work load

Muscular load is assessed by surface *electromyography (EMG)*. The trapezius and infraspinatus muscles and the extensors and flexors of the forearms are of special interest. The activity is normalised to the electric activity during standardised test contractions, either maximal or submaximal. For details on electrodes and skin preparation, see Åkesson et al. 1997. The root mean square value (RMS), calculated for epochs of 1/8 s are used as activity measure, and various percentiles of the amplitude distribution, and the relative duration of muscular rest are used to characterise the load. For recording and signal processing, see Hansson et al. 1997. In spite of the normalisation, there is a large difference between individuals performing the same task (Balogh et al. 1999). Thus, paired measurements, i.e., the same subject performs both (all) work tasks that are of interest to compare, are advantageous. As an alternative, a general linear model may be applied (Hansson et al. in press (a)).

Regarding posture and movements, *inclinometers* are used to measure the orientation of body segments, e.g., head, upper back and upper arms, relative to the line of gravity (Hansson et al. 1992, Åkesson et al. 1997, Hansson & Mikkelsen, 1997). For the head and upper back the forward/backward projection of inclination, and its time derivative is used for describing postures and movements. For the upper arms, elevation, independent of direction, and arm angular velocity is used.

For measuring of wrist positions and movements, biaxial flexible *goniometers* are used (Hansson et al. 1996, Åkesson et al. 1997, Hansson & Mikkelsen 1997, Stål et al. 1999, Hansson et al. in press (b)). Both flexion/extension and radial/ulnar deviation are recorded with a sampling frequency of 20 Hz. From the recorded data, the angular velocity is calculated. Moreover, a generalised measure of repetitiveness, the mean power frequency of the power spectra, is calculated, after performing a fast Fourier transform of the angular data.

Pronation/supination of the forearm is measured with a torsiometer, and software for analysis of these data, deriving the same measures as for wrist positions and movement, is under development. In addition, the data regarding pronation/supination might be used for compensating for the main error in the wrist position measurement. This error is caused by the inherent cross talk of the goniometer, in combination with the pronation/supination of the forearm (Hansson et al. 1996)

To enable recording of the physical/mechanical work load during actual work we use *data loggers* (Asterland et al. 1996). These are based on exchangeable credit-card-sized flash-memories, with a capacity of 20 Mbytes. Hence, in practice, recordings for full workdays can be obtained.

Synchronisation to video recordings

To facilitate synchronisation of the data acquisition with video recordings, a remote-control-unit is used to mark samples in the loggers, and simultaneously light a light emitting diode, which is registered by the video camera. This information is used for, after time coding of the videotapes, digitally synchronise the video-recordings with the measurements. Over four hours of recordings, including interruptions, e.g. exchange of memory cards for the data loggers, a synchronisation error of approximately 1 s was introduced in the earlier measurements. For shorter periods, without interruptions, synchronisation between the loggers and the video-recordings is obtained at a time resolution of one video frame (0.04 s), and the loggers are now being upgraded to accomplish this accuracy even for recordings including interruptions. Moreover, in the studies performed so far, the effect of the synchronisation error could be neglected, since the sensitivity of the derived measures of muscular load, to the synchronisation error, was low (Forsman et al. 1999(a), Forsman et al. submitted for publication).

Defining tasks in production systems

Video recordings are used for evaluation of the production system regarding i.a., productivity. Specialised equipment, consisting of a computer synchronised video recorder and software, is used. Thus, we define appropriate activities, and register them in a file with unambiguous and precise connection to the videotape through time coding (Videolys; Engström & Medbo 1997).

Analyses combining synchronised measurements and video recordings

Muscular load and postures and movements of head, back, upper arms and wrists can be described for the various task activities, as defined by Videolys. Moreover, comprehensive graphs that illuminate the differences between tasks, for a group of operators, are generated. In addition, statistical tests for differences between two (or more) tasks, for each operator, are performed, based on the repeated occurrences of the tasks during one recording (e.g., Christmansson et al. 1999).

The synchronised data for muscular load and postures and movements can be integrated with the video based method for ergonomic evaluation of complex manual work that is used i.a., in COPE (Vidar; Kadefors & Forsman 1997, Kadefors and Forsman submitted for publication). The synchronised data may also be used for evaluation of expert based observation methods (Forsman et al. 1998, Forsman et al. 1999).

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Some comments on exposure measurement tools for the COPE toolbox

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What is the problem?

According to program documents for the COPE program, one of the goals is to optimise production systems both from ergonomic and productivity point of view. Thus a sub-goal is to reduce musculoskeletal disorders caused by work in these production systems. This shall be done by different categories of company staff by providing simple tools for ergonomic evaluation ("COPE tool box").

What causes the problem?

We have today a considerable body of knowledge regarding risk factors for musculoskeletal disorders, mainly concerning work station design and exposure in terms of forces and work postures but also to some extent regarding time aspects and repetition of exposure (Hagberg, et al. 1995, Kilbom 1994a, Kilbom 1994b, Winkel and Westgaard 1992a, Winkel and Westgaard 1992b). One of the goals of COPE is to elucidate the connection between work organisation and physical exposure. The COPE approach is very much based on the idea that predictions for the risk of musculoskeletal disorders can be made based on better estimates of physical exposure.

There are two major complicating conditions that add complications to this approach. The first one is that individual factors like vulnerability, capacity and work technique are strong modifiers of the individual risk (e.g., Bjelle et al. 1981, Hägg et al. 1990, Veiersted 1995, Winkel & Westgaard 1992a, Winkel & Westgaard 1992b). Individual factors also have a strong influence on the outcome of many of the methods used to estimate exposure (see below). The second factor is that psychosocial conditions (demand/control, social support etc.) play a central role for the incidence of musculoskeletal disorders (Karasek & Theorell 1990). These conditions are likely to influence the situation in at least two ways: 1. A bad psychosocial environment and/or stress causes increased and/or prolonged muscle tension increasing the mechanical load on tissues at risk (Wærsted & Westgaard 1996). 2. Negative psychosocial factors are also likely to increase the individual sensitivity for the perception of pain and discomfort.

Which people can do anything about it?

Another key objective in the COPE project is to develop assessment tools to be used by company staff without assistance from external experts. Thus it is essential to identify what groups of personnel that may be involved. A major distinction should be made between, on one hand, company ergonomists and health and safety staff who work full-time with these kinds of issues and, on the other hand, management, engineers and production staff who usually have little background knowledge regarding human aspects of work.

The first category normally has some kind of ergonomic training which make them capable of correctly applying and interpreting simpler exposure measurement methods. The second category can be subdivided into management, product designers and work station designers. For these groups the methods applied have to be related to production and product design concepts. It is not reasonable to expect these groups to learn and consider exposure concepts.

Another important aspect is that the incentives for taking interest in these issues are quite different. While the ergonomist or health and safety officer mostly has a genuine humanistic commitment, the other category has their main interest in economic and/or technical goals of the company. Hence it is of major importance to motivate this category of staff to get involved in ergonomic issues by demonstrating their importance for sick leave and employee turn over costs, productivity and product quality (Eklund 1995, Eklund 1997, Oxenburgh 1991).

Evaluation of different kinds of production change processes

Any viable enterprise of today is characterised by continuous efforts to improve products and production processes (Imai 1986). This fact of course also has consequences for the application of ergonomics. The production process is under continuous surveillance to identify problems regarding productivity, quality and hopefully also worker safety and health. The last aspect is, by the way, mandatory according to Swedish law regarding internal control (”Lagen om internkontroll”).

When discussing the choice of suitable methods for a "tool box", three major classes of changes can be distinguished with specific implications for the choice of tools. In a first category only minor changes are made which implies that the same individuals are doing a modified job after the change. Comparatively accurate individual based measurement approaches can be used and the evaluation is not obscured by large unavoidable interinvidual differences.

In a second class, a major change of a whole unit is carried out which often includes changes of the design of work stations as well as work organisation. If the same individuals are employed at the unit also after the intervention, the conditions for evaluation are principally the same as in the first category. However, if partly or totally new personnel are recruited, the conditions for evaluation are considerably changed as described below.

When creating a totally new production unit with unknown crew, the conditions are different. External exposure can be estimated from technical specifications. Internal exposure can be measured in test subjects in different kinds of simulation models. However great inderindividual differences make estimates uncertain.

What tools can be used?

As mentioned above the choice tools have to be adapted to the background of the user and his/her incentives. Hence the presentation below is divided after staff categories.

Management

On the management level exposure issues are of minor interest. Valid models connecting ergonomics with economics and core values of the company like productivity and product quality are needed.

Product designers

The product designer needs information regarding product manufacturabilitity . This is best communicated to the designer via different kinds of checklists giving simple guidelines for risky postures, forces and weights of objects, e. g. (Svensson and Sandström 1997). It is also essential to make the designer aware of the importance of these issues for productivity and quality.

Production engineers

Also here the main instrument is likely to be different kinds of checklists giving simple guidelines for risky postures, forces and weights of objects (e. g. Svensson & Sandström 1995). Organisational issues of course also have major consequences for the mechanical exposure. In the same way guidelines concerning "work porosity" related to MTM data etc. should be developed.

In addition, important sources of information for both product designers and production engineers are the production operators who are the real experts in cases when not totally new products/production concepts are developed.

Ergonomics and health care professionals

These categories are the only ones that can be expected to use tools where the exposure is estimated. Many exposure assessment tools that are available today are developed for pure research purposes and are in their present versions too complicated to use for the practitioner. The generated data are often excessive with unnecessary accuracy. In some cases available risk models could be integrated in the instrument yielding direct risk indications. Experience from an own survey of corporate initiatives in ergonomics reveal that such programs to very little extent include exposure measurements but rely mainly on crude checklists (Wikström & Hägg 1999).

Different computer based systems for direct systematic observation are available and they are today probably the most adapted instruments for use by these categories. An good example of this is the PEO (Portable Ergonomic Observation) and its more flexible successor PEO-Flex (Fransson-Hall et al. 1995).

Simple EMG equipment mainly designed for feedback and individual training purposes has been available for many years. One development potential is to address time aspects rather than amplitude (Hägg 1997). Such work is under way.

Other examples of methods having a development potential are simple goniometer and inclinometer measurement systems for the wrist, shoulder and back with risk profiles for the respective joint integrated in the system.

Holistic view

Research is mostly characterised by reductionistic approaches. However, when it comes to applications in practice it is important to realise that a holistic view of the situation is important for a successful development of a production organisation. In the introduction above the importance of psychosocial factors was mentioned. In a practical situation such conditions are interacting with physical factors in a complex interplay. Hence, when aiming at effective interventions a holistic approach should be applied integrating physical and psychosocial factors.

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Internationally proposed methods for evaluation of physical work - application and modification for COPE

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Methods used in the COPE programme need to be easily applicable at the workplace and at the drawing-board by non-researchers, i.e. workers, supervisors, designers and Occupational Health and Safety (OHS) staff. Obviously the demands that can be made on these staff categories vary widely. The selection of methods must therefore range from checklists, over qualitative or semi-quantitative methods, to quantitative methods applicable without sophisticated measurements (in actual fact probably no more than measuring tape and stop-watch).

Selection of parameters

The parameters observed and assessed must be selected so as to be generic, i.e. non-specific and applicable to all work situations. There must also be scientific consensus about their potential importance as risk factors for musculoskeletal disorders, implying that rare and poorly substantiated risks must be omitted. Several structures for generic definition of risk factors exist, the most commonly used being a subdivision into manual handling, repetitive work and postures. Winkel and Mathiassen suggest that risk factors should be categorized by force amplitude, repetitiveness and duration (Winkel & Mathiassen 1994). Yet another way of quantifying generic risks is by quantifying postures and forces over time and by body region. In this way different definitions and measures of repetitiveness, forces, and postures can be applied and related to outcomes, i.e. disorders (Kilbom in press). This is, admittedly, a research approach rather than a tool for the layman, but it can be applied when validating COPE methods.

The problem encountered in COPE is to develop methods that are intuitively relevant to the layman, while simultaneously having scientific validity. Thus it must be possible to relate the parameters chosen for the COPE toolbox to one of the generic risk factors. The simplification of methods must also be balanced against a loss of precision. Is a classification of risk in two categories (risk -no risk) sufficient, or will it permit too many risky/non risky situations to go unnoticed? And where should the cut-off level be?

Which methods are available?

Repetitive and/or hand-intensive work

Repetitive work is an important risk factor for many musculoskeletal disorders in the upper extremity. In a guideline from 1994, quantitative risk levels were suggested based on the frequency of movements over certain joints (Kilbom 1994). Repetitive work was defined as the performance of similar work cycles, again and again, with the work output, time sequence, force pattern and spatial characteristics being the same from one cycle to the next. This type of highly repetitive work, subdivided into identical work cycles, still exists in some manufacturing industries. Nevertheless in many modern manufacturing industries these very well-defined cycles, always the same, are gradually changing in character to become more varied in motion pattern. The hands are continuously working, though, but performing different motions and activities over the day, handling different tools, and working on different parts. I would like to term this type of work “hand-intensive” rather than repetitive. In a study by video recording on an automobile assembly line, Fransson-Hall concluded that the hands were active for ca. 85% of the working time, but performing many tasks and using a variety of tools (Fransson-Hall et al. 1996). The wear-and-tear effect on tissues, e.g. due to friction, can be presumed to be somewhat higher if the motion pattern is exactly the same from one cycle to the next. Nevertheless, frictional effects for example in the carpal canal can be high even if the motion pattern is not exactly repeated, as long as awkward wrist postures and high-force handgrips are used.

Up to a few years ago, repetitive work was assessed based on cycle times, work-rest patterns, force exertions and postures (Kilbom 1994, Silverstein et al. 1986) or a combination of all these factors into an index (Moore & Garg 1994, Occhipinti 1998). The validity of such indices with regard to risk has been poorly evaluated, as has their feasibility for use by non-specialists. Recently Latko and co-workers suggested an alternative observational approach, using a rating scale from 0 to 10 where 0 means that the hands are idle most of the time and no regular exertions occur, and 10 signifies rapid steady motion/exertion and difficulty keeping up (Latko et al. 1997). So far the evaluations of this method has demonstrated its usefulness even by non-experts after relatively short training. This method might be a useful alternative to others in COPE, for assessment of hand-intensive work.

General assessment models

Can the non-expert be required to investigate the load on individual regions of the human body? Most expert methods refer to certain body regions (neck, shoulder, wrist, low back) which appears simple for e.g. the physiotherapist/ergonomist. But does the operator/supervisor have sufficient anatomical knowledge to distinguish between e.g. flexion of the lumbar region and the neck region, not to mention the distinction between flexion and flexion/twisting of these regions? For these categories of observers, further simplifications are needed. The checklist PLIBEL developed by Kemmlert appears to be a suitable method. It consists of a set of 16 questions with yes/no answers which, apart from one question on back/neck movements, does not require knowledge of anatomy (Kemmlert 1995). In addition it can be used as a risk assessment instrument when injuries in certain body parts have occurred, but this is an extra bonus not necessary for the simple approach.

An alternative approach when general assessment models are wanted is to use available ergonomic standards, e.g. CEN and ISO regulations. Usually these require quantitative data on forces, durations and distances which have been criticized for their deceptive presumption on accuracy and lack of scientific validation. The Swedish ergonomic standard is preferable, since it has few quantitative limits and risk assessment is based on a three level colour coding approach – green being acceptable, yellow conditionally acceptable and red unacceptable (Swedish National Board of Occupational Safety and Health 1998). Another three-level approach is the cube-model (Kadefors 1997).

Conclusions

Methods for assessment of physical workload for COPE purposes need to be much simpler than previously assumed. Since COPE has access to some very sophisticated methods, some of the simple methods mentioned above should be validated against quantitative data, for further development into COPE tools. The optimal way of linking observed workloads to production technique remains to be solved.

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Some thoughts on what we know and do not know regarding mechanical exposure – health effect relationships: what are the toolbox alternatives?

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State of the art of health ergonomics

Ergonomics aim to promote health and improve performance. In the half century health ergonomics has existed as a professional discipline, a major goal has been to establish the association between mechanical exposure and adverse health effects. This knowledge would then, as a next step, be formulated in guidelines that serve as a basis for workplace interventions. It is therefore a disappointment that problems with putative work-related musculoskeletal problems appear to be as prevalent or more prevalent today than when then health ergonomists first started their work. However, musculoskeletal problems are multifaceted, and many work-related problems or risk factors that are major concerns today, e.g., sustained, low-level exposure and psychosocial problems, were not recognized or even appeared to exist a few decades ago. In addition, the old problems have not gone away, although they presently may receive less attention, at least in the Nordic countries.

A sign of maturity of health ergonomics as a professional discipline, is the recent flurry of review papers and guidelines for acceptable mechanical exposure, covering, e.g., shoulder and neck complaints (Winkel & Westgaard 1992a, Winkel & Westgaard 1992b), low back complaints (Waters et al. 1993, Burdorf & Sorock 1997), hand and low arm complaints (Hagberg et al. 1992), repetitiveness (Kilbom 1994a, Kilbom 1994b), and work-rest schedules (Konz 1998a, Konz 1998b). Several textbooks and CD-roms are issued or being planned (e.g., Industrial and occupational ergonomics: users' encyclopedia by International Journal of Industrial Engineering). Ergonomic standards are prepared at high speed by European, US and International Standards institutes, and by national bodies. Pertinent questions are 1) will adherence to these guidelines/standards fully or partially protect against musculoskeletal health problems at work, 2) what are the limitations to these guidelines, 3) are the guidelines efficient in the many different practical settings, and 4) how can we best ensure implementation in the practical world?

Do guidelines protect against work-related musculoskeletal complaints?

Existing guidelines can be divided in quantitative and qualitative guidelines. Quantitative guidelines are based on biomechanical, anthropometric or physiological considerations, with emphasis on a set of exposure variables with risk potential. The stated limits to exposure should not be exceeded, and the individual variation in tolerance is handled by a population-based approach whereby a limit is supposed to be “safe” for a large fraction of the working population. Such guidelines are biased towards control of exposure amplitude, either by being based on a biomechanical (internal) strain that should not be exceeded, or by avoiding low-level static load or contact stress (e.g., anthropometric guidelines). The time variables of mechanical exposure (repetitiveness, duration) and interaction effects between the conceptual exposure dimensions have so far only been tentatively considered (Kilbom 1994a, Konz 1998a). My belief is that these guidelines, based on biomechanical, physiological and anthropometric considerations, are sensible and contribute to an acceptable workload and good musculoskeletal health. They are available from many ergonomic texts and standards. They function predominantly as design guidelines, aiming to control external exposure amplitude. Aspects of biomechanical exposure, not yet utilized (e.g., tendon travel), may serve as a basis for additional quantitative guidelines. This work must be encouraged, but I doubt that the fundamental solution to work-related musculoskeletal problems is the development of more quantitative guidelines. I feel we can reasonably believe that the traditional risk factors for musculoskeletal complaints at the workplace, amenable to quantitative assessment, are reasonably covered by existing guidelines. This does not preclude future breakthroughs in understanding, but as of today I cannot see that new quantitative guidelines with high impact are emerging.

The qualitative guidelines function more as pointers to risk factors, and need to be interpreted locally. Good examples are some of the more generally formulated Euro-pean standards (e.g., CEN standard 614-1), the new OSHA ergonomics standard (www.osha.gov), and new national standards in the Nordic countries (e.g., Norwegian Directorate of Labor Inspection, no. 531, Heavy and monotonous work). They tend to be more comprehensive than the quantitative guidelines by covering more risk factors, and are equally well suited for the evaluation of existing workplaces as for the design of new ones, but require that ergonomics knowledge is available locally. (The local interpretation would make use of both quantitative guidelines and simplified assessment procedures.) In the local interpretation, it should be realized that ergonomic evaluation can be time-consuming, and an important prerequisite for acceptance of procedures is that they are perceived as user friendly and efficient. If a work task carries a risk of complaints, which is identified by a simple evaluation, there may be little need to put numbers on this risk.

Established guidelines for mechanical exposure: what are the limitations?

Most of the putative work-related musculoskeletal complaints develop at low to moderate mechanical exposure. The time course for the development of complaints is long, and it is not unreasonable to believe that there is perpetuating factors other than mechanical exposure that contribute to the event. A population based approach to the control of risk factors, e.g., accommodating older workers by further lowering the acceptable weight limit for manual handling as a design standard, is probably counterproductive. There is large inter-individual variation in tolerance to low-level biomechanical exposure, and even intra-individual variation over time, suggesting a flexible approach. The subjective response to the mechanical exposure must be assessed and accommodated. The production lines and rationalization strategies must allow for flexibility in the work demands the production system presents to the workers. Some of this flexibility may be handled by engineering design, but is more likely a work organizational issue.

Do valid “objective” (measured) criteria for acceptable exposure at low workloads exist? The answer is probably negative. Extrapolation of quantitative guidelines to low amplitude, long duration exposures retains the population-based assessment procedure. However, the individual variation in tolerance for exposure becomes very large for low-amplitude mechanical exposures. The underlying injury models are likewise unclear. The most popular injury models (e.g., the Cinderella hypothesis) are not easily accomodated by instrumented measurements. Analysis of surface EMG recordings by unusual methods, like EMG gaps, have been able to discriminate workers who develop pain from those that do not in some studies (Veiersted et al. 1993, Hägg & Åström 1997), but not generally so (Vasseljen & Westgaard 1995). Recent research suggests a physiological interpretation of the epidemiological findings: the gap phenomenon appears to promote motor unit substitution; but no established objective criterion for acceptable exposure in terms of EMG gaps is available (Westgaard & De Luca in press). Additional injury mechanisms may exist that involve other physiological systems, e.g. the sympathetic nervous system and its peripheral target organs, in view of the frequent association between stress and musculoskeletal pain. If this is the case, there is at present no method available for objective assessment of such a physiological risk factor.

In conclusion, evaluation for assessment of acceptable mechanical exposure at low exposure amplitudes is likely best based on expert judgement and subjective evaluation. Quasi-objective variables such as reported time in different postures may help in the evaluation, but these variables are rather soft indicators of risk. The use of such variables should be backed up with information on associated, subjectively experienced strain or discomfort, which are possibly a better indicator of risk of future complaints. This is indicated by a longitudinal study where EMG gaps discriminated between those who developed complaints and workers who remained symptom-free (Veiersted et al. 1993), the subjectively experienced work strain at start of work was an even better discriminating variable (Veiersted & Westgaard

1994). In this assessment, a model with three risk dimensions (mechanical exposure, mental stress, and individual sensitivity) may be appropriate. The two latter dimensions can be considered to represent "noise" in the evaluation of effects of mechanical exposure interventions.

How do we optimize the ergonomic guidelines in the practical world ("the toolbox")?

We need to distinguish between guidelines intended for workplace design and those used to assess group or individual risk in existing work situations. With respect to workplace design, an adaptation of existing guidelines (e.g., CEN standards) will probably cover much of the requirements needed to establish a basis for good physical working conditions. In addition, production processes and the physical layout of the production facilities must be optimized to allow for individual flexibility in the mechanical exposure. With respect to the last requirement, it is difficult to formulate more specific guidelines; solutions must be sought locally. Various technical tools for modeling can, however, be of great help in the design process.

How do we best ensure implementation in the practical world?

This will be a key issue for the ergonomics community the coming years. The recent review of ergonomic interventions (Westgaard & Winkel 1997) provides some general clues: both workplace and the individual worker should be targeted for maximal effect. An organizational approach is needed, possibly modeled upon the total quality management tradition and incorporating elements of the human relation tradition. Rationalization strategy and stakeholder commitment is important prerequisites, in particular management support (Winkel & Westgaard 1996). The intervention measures must actively involve the workers. These requirements pose particular challenges for a support group of ergonomists that normally exists separate from the organization that implements the design/intervention measures.

Implementation of ergonomic guidelines in design has proved to be a complex issue where formulation of guidelines is a necessary, but not sufficient step to ensure implementation (Wulff et al. 1999a, Wulff et al. 1999b). Implementation of ergonomic guidelines is a dynamic process that require commitment, stakeholder representation and negotiation skills. General requirements must be translated into specific requirements, and conflicts with other design requirements resolved.

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Finnish experiences in ergonomic assessment

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Scientific research versus practical ergonomic application

In scientific research, the goal is to increase the general knowledge of a theoretically defined problem (table 1). The data are usually collected by quantitative measures and analyzed with statistical methods. The report is written in formal style and the scientific publishers use peer refereeing to guarantee the scientific quality of the published report. Validity aspects are important in the selection of measurement methods. Construct validity refers to "the extent to which the measurement corresponds to theoretical concepts (constructs) concerning the phenomenon under study", and content validity to "the extent to which the measurement incorporates the domain of the phenomenon under study" (Last 1995). In an ideal situation, the measurements should be performed with the best possible instruments. Often these are not available, and even sophisticated instruments have to be calibrated against some external criterion; i.e. against a 'Golden standard' and/or the ability of the instrument to predict the phenomena in the future. The requirement of measures that are as valid as possible increases the costs of a scientific project.

In a practical ergonomic project the goal is to find solutions to specific problems (table 1). The initiators of the project usually have no interest beyond these singular solutions. This means that the approach is more qualitative than quantitative, and the analysis is usually descriptive, concentrating on the problem at hand. The format of the report is particular and the customer may demand the report to be confidential. The validity of the methods is more or less defined by the users of the final solution. The customers are not interested in paying for expensive sophisticated measurements or systematic validation of instruments if new methods are needed. The methods are considered to be valid if they appear to be appropriate ('face validity'). The most important criteria for validity are good enough solutions supported by ergonomic standards.

Different toolboxes for different users

Ergonomics can be applied in the design of new work tasks, places, processes, or tools or in the corrective actions on old ones. In both cases the application of ergonomics is an interactive process where a new design is applied and adjusted according to the feedback from the workers. The cycle, designing - testing - redesigning,

Table 1. Comparison of scientific research and practical applications in ergonomics

	Scientific research	Practical application
Goal	General theory	Singular solutions
Approach	Quantitative	More qualitative
Analysis	Statistical	Problem oriented
Report	Formal, based on general theory	Informal, particular
Validity	Defined by scientists	Defined by users (workers, employers)
	Construct validity	Face validity
	Content validity	
Criterion validity	Sophisticated 'Golden standard'	Predictive validity
	Predictive validity	Ergonomic standards

may be iterated several times, until a good enough solution has been achieved. The constraints in the design of a new work are different from those in corrective actions. Traditional methods (e.g. interviews, observations or measurements) can be used before and after the corrective actions to assess the effects on physical workload (Gael 1988, Kirwan & Ainsworth 1992, Wilson & Corlett 1990). A designer of a totally new work cannot make these kinds of measurements. He/she is limited to previous experience on similar situations and general ergonomic standards. Mock-ups and simulations are some additional options. Today computers enable simulations of 'virtual work'. The training, education and objectives of the designers of new work differ from those of the ergonomists consulting for corrective actions. Therefore, these two groups need different tools for assessing physical workload.

Finnish experiences

The tools used by the ergonomists in Finland have been applications of the traditional ones: interviews, checklists and observations. The reproducibility or validity of only few methods has been formally studied (Kallio et al. submitted, Karhu et al. 1977, Ketola et al. 1996). Video-recording has mainly been used for documentation and as a motivational tool for the workers to invent solutions themselves. Sometimes the video has been combined with EMG recordings. Suitable methods have been disseminated from the experts to the practitioners via courses and publications. Today several checklists are available on the Internet home pages of the Finnish Institute of Occupational Health (http://www.occuphealth.fi).

A human manikin with anthropometric and biomechanical data has been developed for work place designers using AutoCAD (ErgoSHAPE™). Later, more ergonomic data and checklists have been added to the computer software (ErgoTEXT™). In 1991-1994 a program 'Good Design Practice for Workplace Design' was carried out (Launis et al. 1996). Workplace design practices, methods and information systems were investigated, developed and tested in this program. The experiences from the projects were collected and formulated into two computer-based information and tool packages. The first one, ‘Folder for developing design practices’ is intended for carrying out the entire development process in the enterprise. The second package, ‘Toolbox for workplace design projects’ is a selection of information and tools needed in the design project and in design work in general.

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Using exposure profiles in the optimization of working day design?

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Working day design

The Department of Work Physiology at the Danish National Institute of Occupational Health has been involved in studies of physical workplace exposure in several different trades or branches during the last 15 years. Originally, exposure assessments were conducted as individually based measurements of changes in the physiological response during a working day, e.g. electromyographic indications of muscle fatigue during work. However, these individual measurements proved insufficient in providing the required basis for risk assessments and interventions in the working environment.

The focus in the studies through the last 10 years has thus changed to a more general exposure description. Using a group-based exposure assessment strategy, the exposure of the different job tasks involved in a given job is emphasized. The homogenous exposure group approach implies that job task exposure quantification is based on the group, and the groups mean – based on random samples - is assigned to each individual in the group. Total workday exposure can finally be estimated as a time weighted exposure profile on the basis of information on task duration and distribution during a working day. At the same time, the job task becomes the a central basis or the common denominator used in multi-disciplinary projects where other working environment factors than ergonomics are assessed.

Repetitiveness/working postures in relation to job task – homogenous exposure groups?

Non-experts can with some modifications - collect a number of physical (biomechanical) job task exposure data, e.g. concerning repetitiveness or working postures (joint positions)

In a recent study in the slaughterhouse industry, the job task was defined as meat cutting. The frequency and the time with shoulder abduction >30° were registered among 46 meat cutters (table 1).

Table 1. Exposure during meat cutting

	Abduction>30°; number pr. min					Abduction>30°; % working hours				
	N[a]	mean[b]	SD[c]	%SD[d]	range[e]	N[a]	mean[b]	SD[c]	%SD[d]	range[e]
Meat cutting	46	7,5	2,6	34	4-16	46	53,1	11,7	22	27-75

a. number of subjects
b. mean exposure of the group
c. standard deviation between subjects
d. standard deviation in percent of mean
e. range of exposure among subjects

The individual variation was very large for both variables. The number of shoulder positions in a given interval showed more variation (%Standard Deviation, SD, = 34) than the time spent with the arm in a given position (%SD=22).

The term homogenous exposure groups implies that individuals within an identified group have essentially the same mean exposure. It was thus doubtful whether the meat cutters could be characterized as being a homogeneous exposed group. In an attempt to increase the homogeneity and to reduce the individual variation, the meat cutting work was divide into sub-groups with respect to the type of meat being cut, e.g. ham, shoulder part, or belly pork (table 2).

Again individual variation was lowest regarding time with arm abduction of more than 30° (%SD=14-29), whereas the registration of the number of shoulder positions >30° especially for cutting of belly pork showed a very large variation (%SD=53).

Although the job task was now defined as type of cutting - the most detailed description of a working task possible - the individual difference of the movement pattern remained large.

Actually the inter-individual variation in the movement pattern for the different meat cutting types was larger than the variation between the 3 types of meat cutting. This is unfortunate, because in the comparison of occupational groups, it is essential that the variance between groups is larger than the variance within groups, to avoid bias in risk estimates due to overlapping exposures.

Table 2. Exposure during sub-groups of meat cutting work

	Abduction>30°; number pr. min					Abduction>30°; % working hours				
	N[a]	mean[b]	SD[c]	%SD[d]	range[e]	N[a]	mean[b]	SD[c]	%SD[d]	range[e]
Cutting belly pork	15	10,0	5,3	53	5-21	15	54,8	7,8	14	39-67
Cutting shoulder parts	15	7,4	1,5	20	5-20	15	49,8	14,2	29	27-75
Cutting ham	16	6,1	1,5	24	4-9	16	54,6	12,2	22	32-72

a. number of subjects
b. mean exposure of the group
c. standard deviation between subjects
d. standard deviation in percent of mean
e. range of exposure among subjects

Table 3. Ratio (Q) of the mean standard deviation for all exposure groups (n=103) to the standard deviation of the mean value across exposure groups, Data from the PRIM project.

Exposure variable	Mean Standard Deviation	Standard Deviation of the Mean	Q
Hand/Wrist Velocity (scale 1-5)	0,216	1,078	0,1999
Cycle time (sec)	211,278	958,624	0,2204
Shoulder Force (scale 1-5)	0,207	0,688	0,3005
Exertions (number/min)	3,543	10,631	0,3333
Extreme ulnar deviation (% cycle time)	3,048	10,620	0,3464
Duration of exertion (% cycle time)	6,070	14,967	0,4056
Shoulder flexion micropauses (% cycle time)	7,24	13,655	0,5302
Repetitive movements of elbow (number/min)	5,358	9,145	0,5859
Repetitive movements of hand (number/min)	5,873	9,254	0,6347
Repetitive movements of shoulder (number/min)	5,144	7,867	0,6540
Neck flexion >20° (% cycle time)	14,701	22,297	0,6593
Shoulder abduction 0-30° (% cycle time)	13,778	18,055	0,7631[a]
Shoulder flexion >60° (% cycle time)	3,706	4,228	0,8764[a]
Shoulder extension (% cycle time)	5,023	5,597	0,8975[a]
Shoulder flexion 30-60° (% cycle time)	11,334	12,351	0,9177[a]
Shoulder flexion 0-30° (% cycle time)	15,113	14,992	1,0081[a]

a. Q>0,75

Homogenous exposure groups in the PRIM project[1]

The requirement for "functional homogeneity" when comparing differentially exposed occupational groups - i.e. that between group variance is larger than within group variance - became an important criterion in the PRIM project[3]. In this project a large number of task related exposure groups (n = 103) were established. The groups represented a continuum of exposure levels within monotonous, repetitive work and it was thus important that a sufficient contrast between exposure groups could be established.

In table 3, a small selection of the 43 exposure variables used in the PRIM project (representing force, working postures and repetitiveness) is shown. A single number estimate of within and between group variance with respect to the different

[1] PRIM (Project on Research and Intervention in Monotonous Work): prospective cohort study initiated in 1994.

[2] PRIM (Project on Research and Intervention in Monotonous Work): prospective cohort study initiated in 1994.

[3] A number of alternative statistical tests to define homogenous exposure groups exist. Rappaport (1991) proposed that a group of persons could be characterized as homogeneously exposed if 95% of the individual arithmetic mean concentrations was within a factor 2.

exposure variables was obtained by computing the ratio of the mean standard deviation for all exposure groups (within group standard deviation) to the standard deviation of the mean values across exposure groups (between group standard deviation). Low ratio values (Q) indicate that between group variance is the prime source of exposure variance. This was the case for a number of exposure variables linked to work organizational procedures (i.e. cycle time, number of exertions per min, duration of exertion, micropauses), force requirements, and some work postures e.g. extreme ulnar deviation. Problems could on the other hand be seen for a large number of work postures. Despite efforts to optimize group homogeneity by establishing exposure groups based on task equivalence the within-group variance was larger than between-group variance for a number of shoulder postural variables.

As a consequence, variables with ratio values exceeding an arbitrary chosen "cut point" of Q = 0.75 – marked in table 3 – were excluded from subsequent analyses in the PRIM project in order to reduce within-group variance and enhance exposure contrast.

Exposure assessment/risk assessment and working day design

In practical terms, the results indicate that interventions capable of changing work organizational procedures (such as piece rate, flow speed at the assembly line etc) should have a profound and identical effect on exposure levels for all workers in a specific job task. A number of simple "tools" related to product technical measures is thus – in theory - available for the practitioner trying to optimize exposure levels, job task distribution and work day design.

A major problem is however, that a high degree of uncertainty is inherent in the risk assessment process for physical work place exposure. Jayjock and co-workers (1997) emphasized that a detailed and practical risk assessment procedure incorporates a process where workplace exposure is assessed and compared with occupational threshold limit values based on dose-response data. The de facto situation for physical workplace exposures is unfortunate in this context since knowledge about dose/response relationships is insufficient for most of the work-related musculoskeletal disorders.

This is partly due to a limited understanding of the complex relationship between workplace exposure and the relevant tissue dose, which implies that the majority of exposure measurements in epidemiological studies cannot be used for establishing dose/response relationships. In the previously mentioned meat cutter study large differences in work pace were observed among the 48 workers. Six meat cutters worked at a high pace (work cycle time <85% of the mean cycle time) while six other meat cutters worked at a slow pace (work cycle time >120% of the mean cycle time). Despite this marked differences in exposure the surface recorded EMG indicated a similar muscle activation level and pattern in the two groups and electromyographic indications of muscle fatigue were absent in both groups.

As a consequence of these observations a two level preventive/research strategy can be outlined: (1) Workplace interventions aimed at generic risk factors have to be based on existing - often insufficient knowledge. (An obligation to "Act in the face of uncertainty"). For this purpose, job task exposure assessment based on simple product technical or work organizational variables seems to be almost as reliable as more detailed "ergonomic" assessment models; (2) Accept criteria based on valid dose/response relationships should be established. Acknowledging that traditional epidemiological cohort studies alone will be unable to provide the knowledge base needed, research into the mechanisms of the disorders with a view to establish exposure-dose as well as dose-response relationships should be given a high priority.

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Summary

Mathiassen SE och Winkel J (2000) *Ergonomics in the continuous development of production systems. A COPE-workshop on methods for collecting and analyzing mechanical exposure data.* Arbete och Hälsa 2000:6.

A workshop was arranged under the auspices of the R&D program COPE with the purpose of discussing tools by which company stakeholders can assess mechanical exposure (physical workload) as an integrated part of the development of new industrial production systems. Invited Nordic experts gave their opinions on appropriate company-based target groups, relevant exposure metrics, currently available tools, and important lines of further development. The publication contains written contributions from the experts, as well as an introductory chapter presenting the concept of integrated tool development, a summary of the plenary discussion at the workshop, and lines of future R&D inspired by the workshop.

Sammanfattning

Mathiassen SE och Winkel J (2000) *Ergonomics in the continuous development of production systems. A COPE-workshop on methods for collecting and analyzing mechanical exposure data. (Ergonomi i produktionssystem under utveckling. En COPE-workshop om metoder för insamling och analys av data om mekanisk exponering. På engelska)* Arbete och Hälsa 2000:6.

Inom ramarna för FoU-nätverket COPE arrangerades en workshop i syfte att diskutera verktyg som kan användas av företagsaktörer för att bedöma mekanisk exponering (fysisk belastning) som en integrerad del av utvecklingen av nya produktionssystem i industrin. Inviterade nordiska experter gav synpunkter på lämpliga målgrupper på företagen, relevanta mått på exponering, redan tillgängliga verktyg, och viktiga framtida FoU-fågor. Skriften innehåller experternas skriftliga bidrag, samt ett introducerande kapitel som presenterar iden om integrerade verktyg, refererar plenardiskussionen på workshopen, och ger exempel på fortsatta FoU-aktiviteter som inspirerats av workshopen.