Guidance on the application of the essential health and safety requirements on ergonomics set out in section 1.1.6 of Annex I to the Machinery Directive 2006/42/EC

The guidance provided in the following documents is complementary to the Guide to application of the Machinery Directive 2006/42/EC, in particular, to §181 of the Guide

Contents

— The family of harmonised standards developed by CEN TC 122 – *Ergonomics* to support the Machinery Directive's application.

— Relationship between the ergonomic factors mentioned in section 1.16 of Annex I and the family of standards developed by CEN TC 122 – *Ergonomics*.

— Guidance sheets on each of the ergonomic factors mentioned in section 1.1.6 of Annex I and their possible negative consequences:

- Operators variability
- Space of movements
- Work rate
- Concentration
- Human/Machine interface
- Physical stress
- Psychological stress
- Discomfort
- Fatigue

The family of harmonised standards developed by CEN TC 122 – *Ergonomics* to support the Machinery Directive's application

Table prepared on the basis of the information provided on the CEN website:

Standard reference	Title	Citation in OJ	Directive
EN 1005-1:2001+A1:2008	Safety of machinery - Human physical performance - Part 1: Terms and definitions	Expected	98/37/EC, 2006/42/EC
EN 1005-2:2003+A1:2008	Safety of machinery - Human physical performance - Part 2: Manual handling of machinery and component parts of machinery	Expected	98/37/EC, 2006/42/EC
EN 1005-3:2002+A1:2008	Safety of machinery - Human physical performance - Part 3: Recommended force limits for machinery operation	Expected	98/37/EC, 2006/42/EC
EN 1005-4:2005+A1:2008	Safety of machinery - Human physical performance - Part 4: Evaluation of working postures and movements in relation to machinery	Expected	98/37/EC, 2006/42/EC
EN 547-1:1996+A1:2008	Safety of machinery - Human body measurements - Part 1: Principles for determining the dimensions required for openings for whole body access into machinery	Cited in OJ C 22 (2009-01-28)	98/37/EC, 2006/42/EC
EN 547-2:1996+A1:2008	Safety of machinery - Human body measurements - Part 2: Principles for determining the dimensions required for access openings	Cited in OJ C 22 (2009-01-28)	98/37/EC, 2006/42/EC
EN 547-3:1996+A1:2008	Safety of machinery - Human body measurements - Part 3: Anthropometric data	Cited in OJ C 22 (2009-01-28)	98/37/EC, 2006/42/EC
EN 614-1:2006+A1:2009	Safety of machinery - Ergonomic design principles - Part 1: Terminology and general principles	Expected	98/37/EC, 2006/42/EC
EN 614-2:2000+A1:2008	Safety of machinery - Ergonomic design principles - Part 2: Interactions between the design of machinery and work tasks	Expected	98/37/EC, 2006/42/EC
EN 842:1996+A1:2008	Safety of machinery - Visual danger signals - General requirements, design and testing	Cited in OJ C 22 (2009-01-28)	98/37/EC, 2006/42/EC
EN 894-1:1997+A1:2008	Safety of machinery - Ergonomics requirements for the design of displays and control actuators - Part 1: General principles for human interactions with displays and control actuators	Expected	98/37/EC, 2006/42/EC
EN 894-2:1997+A1:2008	Safety of machinery - Ergonomics requirements for the design of displays and control actuators - Part 2: Displays	Expected	98/37/EC, 2006/42/EC
EN 894-3:2000+A1:2008	Safety of machinery - Ergonomics requirements for the design of displays and control actuators - Part 3: Control actuators	Expected	98/37/EC, 2006/42/EC
EN 981:1996+A1:2008	Safety of machinery - System of auditory and visual danger and	Cited in OJ C 22 (2009-01-28)	98/37/EC,

	information signals		2006/42/EC
EN ISO 13732-1:2008	Ergonomics of the thermal environment - Methods for the assessment of human responses to contact with surfaces - Part 1: Hot surfaces (ISO 13732-1:2006)	Cited in OJ C 22 (2009-01-28)	98/37/EC, 2006/42/EC
EN ISO 13732-3:2008	Ergonomics of the thermal environment - Methods for the assessment of human responses to contact with surfaces - Part 3: Cold surfaces (ISO 13732-3:2005)	Cited in OJ C 22 (2009-01-28)	98/37/EC, 2006/42/EC
EN ISO 14738:2008	Safety of machinery - Anthropometric requirements for the design of workstations at machinery (ISO 14738:2002, including Cor 1:2003 and Cor 2:2005)	Cited in OJ C 22 (2009-01-28)	98/37/EC, 2006/42/EC
EN ISO 15536-1:2008	Ergonomics - Computer manikins and body templates - Part 1: General requirements (ISO 15536-1:2005)	Cited in OJ C 22 (2009-01-28)	98/37/EC, 2006/42/EC
EN ISO 7250:1997	Basic human body measurements for technological design (ISO 7250:1996)	Cited in OJ C 336 (2005-12-31), C 78 (1998-03-13), C 252 (2000-09-02), C 192 (2003-08-14)	98/37/EC, 89/392/EEC
EN ISO 7731:2008	Ergonomics - Danger signals for public and work areas - Auditory danger signals (ISO 7731:2003)	Cited in OJ C 22 (2009-01-28)	98/37/EC, 2006/42/EC

CEN/TC 122- Candidate harmonised standards under development

	Project reference	Title	Candidate Citation	Current status	DAV
00122156	prEN 894-4	Safety of machinery - Ergonomics requirements for the design of displays and control actuators - Part 4: Location and arrangement of displays and control actuators	Yes (98/37/EC, 2006/42/EC)	Under Approval	2010-03

Update: 2010-07

Relationship between the ergonomic factors in Annex I – 1.1.6 and the family of standards developed by CEN/TC 122 - *Ergonomics*

The aim of the following table is to illustrate which of the fundamental ergonomic factors mentioned in section 1.1.6 of Annex I is already – at least partially – covered by the standards developed by CEN/TC 122 – Ergonomics.

Essential ergonomic factors in Annex I - 1.1.6 of the Machinery Directive	Specific aspets related to those factors	A and B-type Harmonized Standards available in the work programme of CEN TC 122 listed in the OJ
Operator's variability	physical dimension	EN547-1:1996 + A1:2008 EN 547-2:1996 + A1:2008 EN547-3:1996 + A1:2008 EN 614-1:2006 +A1:2009 EN 894-3: 2000+A1:2008 EN 894-4:2010 EN1005-1:2001+A1:2008 EN1005-4 :2005+A1:2008 EN ISO 14738 :2002 EN ISO 15536-1 :2008
	strength	EN 614-1:2006 +A1:2009 EN1005-1:2001+A1:2008 EN1005-2:2003+A1:2008 EN1005-3:2002+A1:2008 EN ISO 15536-1:2008
	stamina	
Space for movements	posture	EN 547-1:1996+A1:2008 EN 547-2:1996+A1:2008 EN 614-1:2006 +A1:2009 EN 894-3: 2000+A1:2008 EN 894-4:2010 EN1005-1:2001+A1:2008 EN1005-2:2003+A1:2008 EN1005-3:2002+A1:2008 EN1005-4 :2005+A1:2008 EN ISO 14738 :2008 EN ISO 15536-1 :2008
	dynamic	EN 547-1:1996+A1:2008 EN 547-2:1996+A1:2008 EN 614-1:2006 +A1:2009 EN 614-2:2000 +A1:2009 EN 894-2: 1997+A1:2008 EN1005-1:2001+A1:2008 EN1005-4 :2005+A1:2008 EN ISO 14738 :2008 EN ISO 15536-1 :2008
Work rate	pace	EN1005-3:2002+A1:2008
	speed	EN 894-1: 1997+A1:2008 EN 894-3: 2000+A1:2008 EN 894-4:2010
Concentration	vigilance	
	mental operations	EN 614-1:2006 +A1:2009 EN 894-4:2010
	cognitive performance	EN 614-1:2006 +A1:2009 EN 614-2:2000 +A1:2009 EN 894-4:2010
Man/machinery interface	visual	EN 614-1:2006 +A1:2009 EN 614-2:2000 +A1:2009 EN 842:1996 + A1 :2008 EN 894-2: 1997+A1:2008 EN 894-3: 2000+A1:2008 EN 894-4:2010 EN 981 :1996 + A1 :2008 EN ISO 14738 :2008

	auditory	EN 614-1:2006 +A1:2009 EN 894-2: 1997+A1:2008 EN 981 :1996 + A1 :2008 EN ISO 7731:2008
	sensitivity (to tactile tasks)	EN 894-2: 1997+A1:2008 EN 894-3: 2000+A1:2008
	Sensitivity (to temperature)	EN ISO 13732-1:2008 EN ISO 13732-3:2008
	sensory	EN 614-2:2000 +A1:2009 EN 894-2: 1997+A1:2008

Sheet OPERATORS' VARIABILITY:

Last review: 2010-02-10, edited 2011-03-04

BASICS:
Ergonomics deals with interactions among human and other elements of a system. Human beings, however, are different in their attributes. Some attributes are inherent and therefore normally remain constant throughout life, e.g. gender or height. Others change but cannot be influenced, e.g. age. Furthermore, there are attributes which can be influenced considerably, e.g. experience, knowledge, technical skills.

EXPLANATION:

- gender: influences body dimensions and physical attributes
- body dimensions and build: differ with gender and age
- age: affects physical strength, ability to move and sensory perception
- body weight: is inherent and can be influenced by many factors
- state of health: has genetic and social dimensions
- physical strength and performance: is dependent on genetic disposition but also on behaviour, training and short term variation
- qualification, experience: determine the operator's skills, differ with age and task

Work equipment is designed for and placed on the European internal market. It must be usable by men and women in workforce and by people from all European countries.
Most of the body dimensions, build and gender are inherent. Body dimensions may vary from region to region. Younger people are on average taller than older people and show different proportions and degrees of agility. Although age changes, age-related adverse effects can be partly compensated by training and/or assistive technology. Other adverse effects of age can be compensated by different strategies: Older people have more experience and higher decision-making abilities.
Physical strength can be trained, experience can be channelled to a certain extent, qualification can be acquired. Individual performance (e.g. vigilance) and capacity will vary not only with age, but even throughout a working day.

Good equipment design according to basic ergonomic principles supports healthy work for all operator groups, independent of body dimensions, gender, age, cultural background and disabilities. In short: Ergonomic design is one of the best form of prevention in terms of OSH matters. For an ergonomic design EN 614-1 requires at least the 5^{th} to 95^{th} percentiles to meet the intended operator population; for safety aspects, however, the 1^{st} and/or 99^{th} percentiles shall be used. Body dimensions (anthropometric data) are the basis for all design processes. Most of the values (body length, arm or leg length etc.) are normally distributed according to Gauss; values for percentiles can therefore be determined easily. EN 547 provides concrete data. When determining clearance (such as leg room), 95^{th} percentile values should be used; for reach (e.g. operator reach), 5^{th} percentile values are correct. Good design aims for adjustability: a working height that can be set to different positions, or chairs that can be adjusted to suit both short and tall people etc.
In a similar manner, standards provide guidance concerning postures, body movements and physical strength. Quantitative guidance is offered by type B standards. EN 1005 parts 1 to 4 deal with manual materials handling, recommended force limits, working postures and movements, and repetitive loads of the upper limbs during machinery operation. Body strength, however, strongly differs with gender and age.
Only few of the mentioned human attributes can be described in the form of a distribution to identify 5^{th} and 95^{th} percentiles. If no data is available, prototype testing will be a helpful mean where the test group is typical for the expected operator population.
The work and task design has to be considered. Try to get feed-back from the shop floor, where the machinery is used.

STANDARDS:

EN 547-1+A1 : 2008 Safety of machinery - Human body measurements - Part 1: Principles for determining the dimensions required for openings for whole body access into machinery

EN 547-2+A1 : 2008 Safety of machinery - Human body measurements - Part 2: Principles for determining the dimensions required for access openings

EN 547-3+A1 : 2008 Safety of machinery - Human body measurements - Part 3: Anthropometric data

EN 614-1+A1 : 2009 Safety of machinery - Ergonomic design principles - Part 1: Terminology and general principles

EN 1005-1+A1 : 2008 Safety of machinery - Human physical performance - Part 1: Terms and definitions

EN 1005-2+A1 : 2008 Safety of machinery - Human physical performance - Part 2: Manual handling of machinery and component parts of machinery

EN 1005-3+A1 : 2008 Safety of machinery - Human physical performance - Part 3: Recommended force limits for machinery operation

EN 1005-4+A1 : 2008 Safety of machinery - Human physical performance - Part 4: Evaluation of working postures and movements in relation to machinery

EXAMPLES:

N°1

Safe tools at presses must assure that – as in this case – the operator's fingers cannot be put into the danger zones. The slot for material must be small enough that even tiny fingers cannot be inserted.

In this case the 1st to 99th percentile has to be addressed.

N°2

The manual tool exchange at a turning machine is not feasible for left-handed and right-handed people in the same good and ergonomic way. The best direction for applied force is towards the body, which in most cases is not possible for left-handed people.

Furthermore, the force needed for well-fixed tools must not exceed the maximum force possible for the 5th percentile of physical strength.

Sheet Space of movement:

Last review: 2010-02-10, edited 2011-03-04

BASICS:

Proper design will ensure sufficient space for all operators affected to handling the machinery (installing, operating, adjusting, maintaining, cleaning, dismantling, repairing, transporting), the equipment, raw material and products, for the intended use and any reasonably foreseeable misuse. Sufficient space of movement for workers is one of the basic principles in machinery design to prevent accidents and occupational diseases, e.g. musculoskeletal disorders or psychological stress. Appropriate body movements are indispensable to avoid physical stress and strain , support productivity and good work results. Space of movement is essential for the workplace design, whole body access and circulation and all access openings. Size and dimension of workplace design is dependent on the anthropometrical data of the staff and their work tasks.

EXPLANATION :

1 ergonomic body postures
2 avoid static postures
4 body dimensions
5 make way(provide space) for tools and component parts
6 free access to machinery and equipment
7 visibility
8 circulations
9 accesses without obstacles and enough space
10 technical organisation of the space

Ergonomic design decreases physical strains and occupational accidents.

Low space for movement advance these risks. Workers tasks are not limited to regular function and automatic mode. Also maintenance, troubleshooting, repairing and installing machinery are essential and may imply occupational risks. Access openings may concern these risks as well as adequate workplace design. Working postures as sitting, standing, trunk bending, kneeling and tasks with arms above shoulderheight can be critical if posture is static for longer periods. Working posture is dependent on body dimensions and therefore machinery should be designed with respect to expected user population and ideally adjustable in its dimensions.

STANDARDS:

EN 547-1+A1 : 2008 Safety of machinery - Human body measurements - Part 1: Principles for determining the dimensions required for openings for whole body access into machinery
EN 547-2+A1 : 2008 Safety of machinery - Human body measurements - Part 2: Principles for determining the dimensions required for access openings
EN 547-3+A1 : 2008 Safety of machinery - Human body measurements - Part 3: Anthropometric data
EN 614-1+A1 : 2009 Safety of machinery - Ergonomic design principles - Part 1: Terminology and general principles ; chapter 4.3.4
EN 1005-4+A1 : 2008 Safety of machinery - Human physical performance - Part 4: Evaluation of working postures and movements in relation to machinery
EN 1005-5 : 2007 Safety of machinery - Human physical performance - Part 5: Risk assessment for repetitive handling at high frequency
EN ISO 14738 : 2008 Safety of machinery - Anthropometric requirements for the design of workstations at machinery (ISO 14738:2002, including Cor 1:2003 and Cor 2:2005)

EN ISO 7250 : 1997 Basic human body measurements for technological design (ISO 7250:1996) / Note: To be replaced by FprEN ISO 7250-1 (2009-09)
IEC 60204-1, CEI 60204-1 : 2005 Safety of machinery - Electrical equipment of machines - Part 1: General requirements / Note: This document and its separate amendments continue to be valid together with the consolidated version. – chapter 11
IEC 60204-1 AMD 1, CEI 60204-1 AMD 1 : 2008 Safety of machinery - Electrical equipment of machines - Part 1: General Requirements; Amendment 1

EXAMPLES:

N°1
Example for a bad designed workplace: limited space for the legs and awkward body posture.

N°2
Measurement based field study of the static postures and dynamic activities on a well designed assembly workplace. Puppet’s yellow curves are showing the movement of the wrist and ankle joint. Movement is driven by a motion capturing system.

Sheet WORK RATE: final version: 2011-02-16, edited 2011-03-04

BASICS:
The WORK RATE is a flow that describes the number of pieces per time unit measured at one operator's working station. When non adjustable by the operator(s), the work rate imposed by the machine could cause problems.
The designer should also consider two other WORK RATES in order to assess the total work rate:

1. The MENTAL work rate which refers to the number and the complexity of the mental operations to perform.
2. The SENSORIAL work rate that is present when one or several sensory systems are involved in repetitive demands in order to execute visual, acoustic or haptic (sense of touch) requiring tasks. E.g. perception (sensorial task) of / responses from signals, controls, forms and surfaces, pressure, dosage of acceleration, etc. assessed in order to understand and take a decision.

EXPLANATION:
„The individual should be allowed full control of his work rate. During machine operation, the operator should be able to activate and deactivate the machinery at any instant" (EN 1005-3).

The work rate is perceived by the operator as a work demand. Each simple work demand added to the other ones, of different nature, result into the total workload put on the worker. The work rate is often multidimensional: seldom of a single nature, combining physical, mental and/or sensorial dimensions. This combination can result in a balanced work rate or an imbalanced one: when it is balanced, it is then perceived by the worker as an acceptable demand.

A negative perception can effectively be avoided, if each operator has the possibility to adapt the work rate to its own perception and, even, to his/her varying abilities and feelings under a working shift. Letting a machinery impose its rate to an operator is a common mistake that often brings lots of consequences for the human being and for the company.

Each single component of the work rates is easily measurable, the final work rate is sometimes more complex when it results of the three combined work rates. The work rates are a part of the different job demands put on the worker. When these demands are perceived as too high they will provoke at the operator's level negative reactions such as physical or psychological; they will then impact the production.

The most common complaints when the work rate is too high and/or not controllable by the operator and if recovery periods are absent or too rare, are (1) neck-shoulder and arm-hand pain, (2) low back pain, (3) pain in lower limbs, (4) psychological distress associated to low back pain and/or neck and shoulder pain when higher demands, lower job control and poor social support are combined.
Such disorders and complaints can effectively be minimized by design if special attention is paid from the earliest designing stage to ergonomics: in the daily practice, this means leaving to the operator higher degrees of choices and of freedom in order to adjust personally the system for rate or pace, range of motion, posture, height, reaching distance, starting and stopping easily the machine when needed, etc. and by avoiding systematically to load the operator with demands that could be done mechanically or electronically.

Even organisational consequences of a too high work rate can be effectively reduced through ergonomics' principles application at the earliest designing stage.

STANDARDS:

EN 614-1+A1 : 2006 Safety of machinery - Ergonomic design principles - Part 1: Terminology and general principles
EN 614-2+A2 : 2000 Safety of machinery - Ergonomic design principles - Part 2: Interactions between the design of machinery and work tasks
EN 1005-1+A1 : 2008 Safety of machinery - Human physical performance - Part 1: Terms and definitions
EN 1005-2+A1 : 2008 Safety of machinery - Human physical performance - Part 2: Manual handling of machinery and component parts of machinery
EN 1005-3+A1 : 2008 Safety of machinery - Human physical performance - Part 3: Recommended force limits for machinery operation
EN 1005-4+A1 : 2008 Safety of machinery - Human physical performance - Part 4: Evaluation of working postures and movements in relation to machinery
EN 1005-5 : 2007 Safety of machinery - Human physical performance - Part 5: Risk assessment for repetitive handling at high frequency
ISO/FDIS 12100:2010-07 Safety of machinery — General principles for design — Risk assessment and risk reduction

EXAMPLES:

High work rate: repetitive work on a conveyer belt (fruits' packaging)

Sheet CONCENTRATION Last review: 2011-04-14

BASICS:

If the ergonomic factor *concentration* is not taken into account by machinery designers the risk of unintended behaviour of the operator or reasonably foreseeable misuse of the machine occurs (see also EN ISO 12100-1:2003, clause 5.3 (c)). In this sheet it will be assumed that the term *vigilance* corresponds to a sustained concentration ability.

If machinery design involves tasks requiring heavy workload, lengthy or intense concentration/sustained attention, the effect on the operator can be monotony and reduced vigilance. Both an overload and an underload affecting concentration can lead to mental fatigue, monotony and reduced vigilance. Lighting, climate, noise, odours are other factors affecting concentration.
These two fatigue-like states are key contributing factors to human error and increase the risk of incidents and accidents.

Concentration has strong connections with work rate, fatigue and man-machine interface: related sheets should be read conjointly.

EXPLANATION:

An optimal level of concentration can be achieved by:

1. Varying the tasks. It includes job enrichment and job enlargement achieved by means of :
    a. Alternating physically-demanding tasks with perceptually demanding tasks;
    b. Alternating long-cycle tasks with shorter cycles ones;
    c. Providing for frequent changes of posture, at least once per hour;

2. Make the job easier to do. For operators inspecting or monitoring machines this includes making easier the detection of a defect or changed machine status by means of:
    a. Increasing the intensity (colour, shape, marking) of the defect;
    b. Provide redundancy in alarms so that more than one sense is involved;

Research evidence:

1. Vigilance decreases the longer the period of supervisory duty (the decline begins to be evident after the first 30 minutes);
2. Observational performance increases if the signals are more frequent, stronger, more distinct in shape or contrast, and the operator is informed about his/her own performance.

Excessive heat, humidity, poor ventilation, noise, odours and poor operator comfort (no attention to the location of tools, buttons etc) also contribute to losses of concentration.

Today's work with machines tend to require less physical body movement and more cognitive attention and concentration. In particular, when the output, rate and speed of a task is controlled by a machine, the worker is subject to intense concentration.

Moreover, running a production machine can require the operator to do several tasks in the same time period, such as loading supplies and removing the product and inspecting it. This need to accomplish several tasks simultaneously requires concentrated mental effort from the operator and often results in the machine controlling the operator. This stress and the time pressure stress are significant contributors to overall job demands.

Among the design factors relating to machines, operability plays a major role. Operability includes the information load factor, that designers need to take into account in order to avoid overloading or underloading the capacity to receive and process information.

System monitoring with either rare or no response requirements
The more effort (e.g. processing capacity) the operator expends on the task, the less capacity remains available for other tasks or circumstances that may demand attention.

The following key points relate to attention and vigilance:

1. Attention is a fundamental cognitive process that is important to higher level cognitive processes
2. Vigilance requires attention and describes an individual's state of alertness, watchfulness and preparedness to attend to critical information that is not yet present
3. Attention and vigilance are not constant and may be impacted by environmental factors such as noise and temperature.
4. Task factors such as frequency of signals can affect performance on attention and vigilance tasks. Research shows that
    a. Low number of critical signals significantly reduces performance (expressed in reaction time) during a vigilance task.
    b. More non-critical signals per minute results in greater distraction and greater difficulty in identifying critical signals

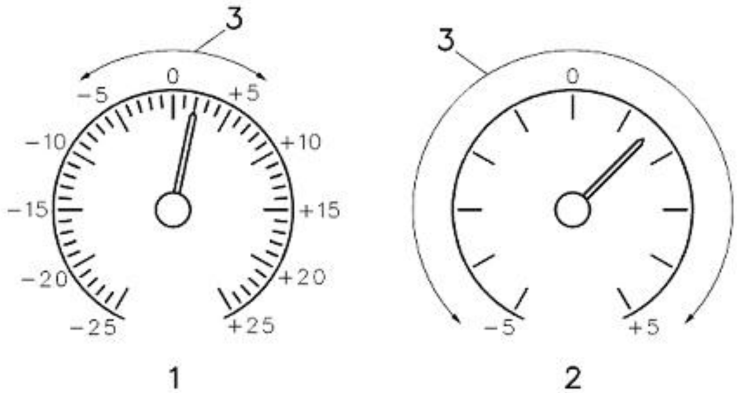
STANDARDS
The machinery designers will find guidelines on how to take into account concentration by means of a coordinated analysis of three harmonised standards:

EN ISO 10075-1 *Ergonomic principles related to mental work-load - Part 1: General terms and definitions* identifies sustained attention as one of the task requirements considered as contributory factor to mental stress.

EN 894-1:1997+A1:2008 *Safety of machinery - Ergonomics requirements for the design of displays and control actuators - Part 1: General principles for human interactions with displays and control actuators* puts monotony and reduced vigilance in the context of the broader subject of human information processing. Recommendations are given to designers to consider if the planned allocation of a particular function in a man-machine system is in accordance with human capabilities, especially in order to avoid overloading the attentional resources of the operator. EN 894-1 is precise in warning that simple and repetitive/monotonous tasks, and tasks that demand continuous attention (like prolonged routine monitoring) have the potential to affect performance in terms of slower reaction times and missed information.

ISO 10075-2:1996 *Ergonomic principles related to mental workload - Part 2: Design principles* provides detailed guidelines on how machinery designers can avoid problems with monotony and reduced vigilance.

EXAMPLE:



Legend:

1 inappropriate

2 recommended

3 used area

Sheet HUMAN-MACHINE INTERFACE

Last review: 2010-02-10, edited 2011-03-04

BASICS:
Healthy and safe interaction of operators with work equipment can be assured if the design of the human-machine interface takes into account ergonomic principles and safety requirements, possibly considering feed-back from the users experience. Human-machine interface design primarily concerns the *task interface*, which defines the functions to be performed by the operator and by the machinery (e.g. allocation of functions, EN 614-2). The design also concerns the *interaction interface*, which tailors the dialogue between operators and machinery (e.g. design of displays and controls, EN 6385, EN 894, EN ISO 9241-110). The task and interaction interfaces are intimately connected, and the interface design serves specified tasks, operational modes and operator qualifications.

EXPLANATION:

- If the human-machine interface is considered at an early design stage, the task design can be better adapted to the needs of the operator
- An important characteristic of an ergonomically designed operator task is its measured diversity (not only monotonous “left over tasks”)
- Qualifications and experience are foreseeable characteristics of the operator; conventions/stereotypes must be considered (e.g. green never stands for danger)
- The design of human - machine interface has to be conform to the expectation of the user
- Readable displays serve operator information acquisition and analysis
- Replacing memory load with e.g. visual or acoustic information, and presenting information in parallel when it is required in parallel, will help the operator to process the information
- Control feedback suitable for the task helps the operator to implement the information

The initial decisions in system design – e.g. on automation involvement – already determine how functions are divided between the human being and the machinery. Operator tasks can only be ergonomically well-designed if the three main *operator task components* (i.e. planning, processing and evaluating) are equally considered at an early stage. High levels of automation, and so called *left over tasks* for the operator (i.e. the operator is only there for carrying out those tasks of which the machine is not capable) are examples of ergonomically bad design. It is necessary that minimally required operator qualification, experience and skill levels be adequately communicated (EN 614-2, EN 11064-1).
The design of the *interaction interface* must be based on dialogue principles for operator-task relationships (EN 894-1, EN 9241-110) and human physical and mental charateristics such as physical strength (EN 1005) and human information processing (EN 894-1). E.g., controls must be adapted to the task and to the operator, the same is true for form, dimension (e.g. grip width) and material/ surface texture, force limits, frequency of operation, posture (affects e.g. type of grip) and type and direction of movement of the control (turning, pulling…). The designer has to avoid unclear instructions, too many steps without feed back information, insufficient lightening, too much information at the same time, unfavourable posture, poorly respected reflex behaviour, stimulation of manipulation of safety devices. For each task and operating mode different solutions concerning the choice and presentation of displays and controls may be suitable. Human perceptional and attentional processes will be supported by information presentation suitable for the task (e.g. in bright environments choose positive polarity displays and controls for clear and umambigous presentation, EN 894-2; choose digital displays only if exact values are required; provide analogue displays for estimates or relative measures; provide trend displays for level over time, EN 894-2; limit working memory demand by integrative displays, EN 10075-2). Dialogue principles such as self-descriptiveness and controllability determine whether feedback design is readily identifiable for the operator (e.g. feedback about operating mode in understandable technical terms). Conformity with user expectations refers e.g. to compatibility or conventions (for instance, turning purging valve to the left increases flow, but turning dial to the right increases speed; red colour indicates danger). Error tolerance may allow the operator to correct potential errors. Further specifications and examples are given in EN ISO 9241-110 or EN 894-1.

STANDARDS:

EN 614-1+A1 : 2009 Safety of machinery - Ergonomic design principles - Part 1: Terminology and general principles

EN 614-2+A1 : 2008 Safety of machinery - Ergonomic design principles - Part 2: Interactions between the design of machinery and work tasks

EN 894-1+A1 : 2008 Safety of machinery - Ergonomics requirements for the design of displays and control actuators - Part 1: General principles for human interactions with displays and control actuators

EN 894-2+A1 : 2008 Safety of machinery - Ergonomics requirements for the design of displays and control actuators - Part 2: Displays

EN 894-3+A1 : 2008 Safety of machinery - Ergonomics requirements for the design of displays and control actuators - Part 3: Control actuators

EN 1005-1+A1 : 2008 Safety of machinery - Human physical performance - Part 1: Terms and definitions

EN 1005-2+A1 : 2008 Safety of machinery - Human physical performance - Part 2: Manual handling of machinery and component parts of machinery

EN 1005-3+A1 : 2008 Safety of machinery - Human physical performance - Part 3: Recommended force limits for machinery operation

EN 1005-4+A1 : 2008 Safety of machinery - Human physical performance - Part 4: Evaluation of working postures and movements in relation to machinery

EN 1005-5 : 2007 Safety of machinery - Human physical performance - Part 5: Risk assessment for repetitive handling at high frequency

EN ISO 6385 : 2004 Ergonomic principles in the design of work systems (ISO 6385:2004)

EN ISO 9241-12 : 1998 Ergonomic requirements for office work with visual display terminals (VDTs) - Part 12: Presentation of information (ISO 9241-12:1998)

EN ISO 9241-110 : 2006 Ergonomics of human-system interaction - Part 110: Dialogue principles (ISO 9241-110:2006)

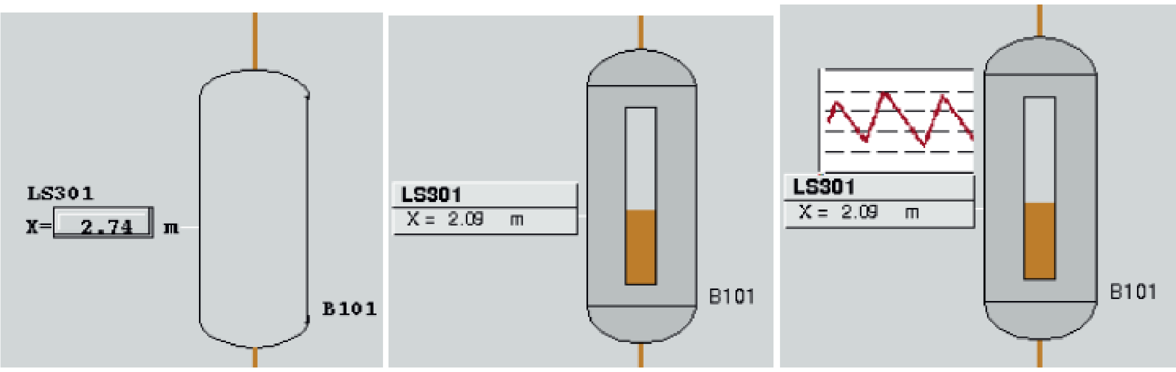
EN ISO 10075-2 : 2000 Ergonomic principles related to mental workload - Part 2: Design principles (ISO 10075-2:1996)

EN ISO 11064-1 : 2000 Ergonomic design of control centres - Part 1: Principles for the design of control centres (ISO 11064-1:2000)

EN 13861 : 2002 Safety of machinery - Guidance for the application of ergonomics standards in the design of machinery

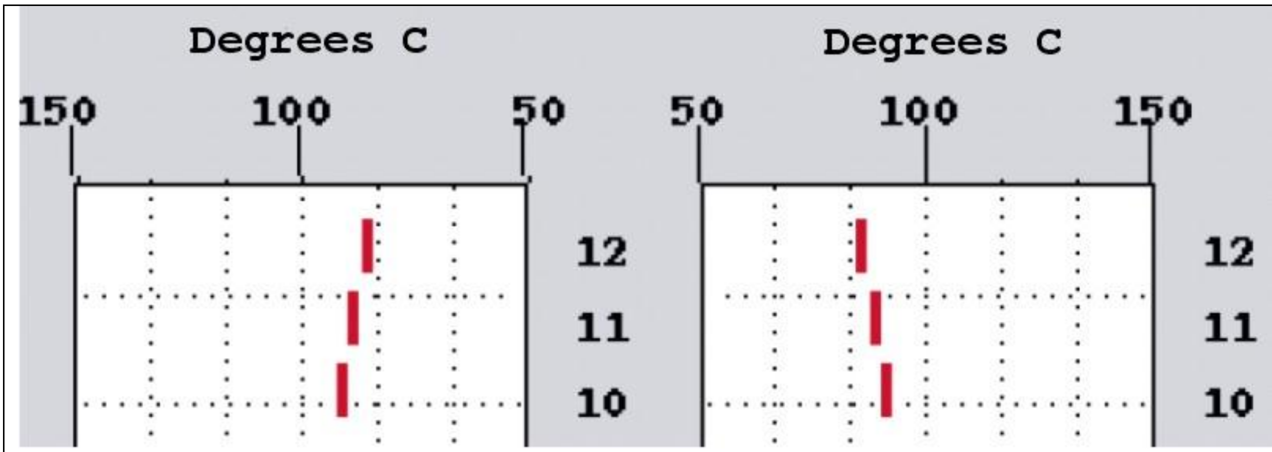
EN 60447 : 2004 Basic and safety principles for man-machine interface - Marking and identification - Actuating principles (IEC 60447:2004)

EXAMPLES:



Source: University of Oldenburg

N° 1: Display with (a) digital (b) analogue and (c) dynamic (trend-supported) tank level feedback.

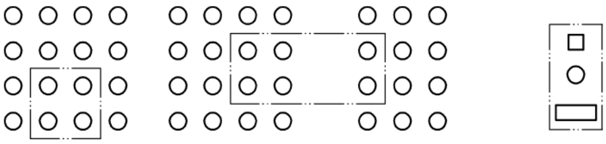


Source: University of Oldenburg

bad **good**

N° 2: Display with scale violating conventions/stereotypes (left) and respecting stereotypes (right)

Figure 6 — Related elements grouped by proximity



a) **within a group**
NOTE for instance to make differing elements clearly visible as a group

b) **between adjacent groups**
NOTE for instance to make differing elements clearly visible as a group

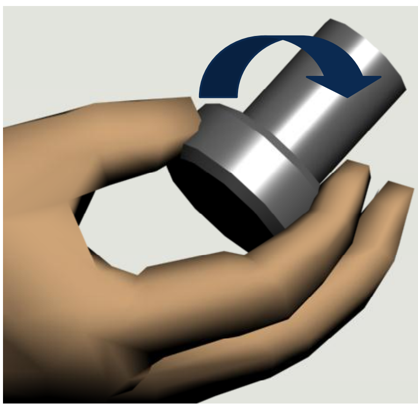
c) **to make different elements clearly visible as a group**

Figure 9 — Effect of framing

Source : ISO DIS 9355-4:2004
(Figure 6 - Related elements grouped by proximity;
Figure 9 - Effects of framing)

N° 3: Allocation of displays and/or controls to different tasks or operating modes (e.g. principle of proximity and framing

N° 4



Round form creates the expectation that the operator has to turn the control

No 5

Multifunctional control on a wheel loader
Good layout for reaching all buttons, counter-sunk buttons avoid accidental operation, special surface configuration for better haptic perception

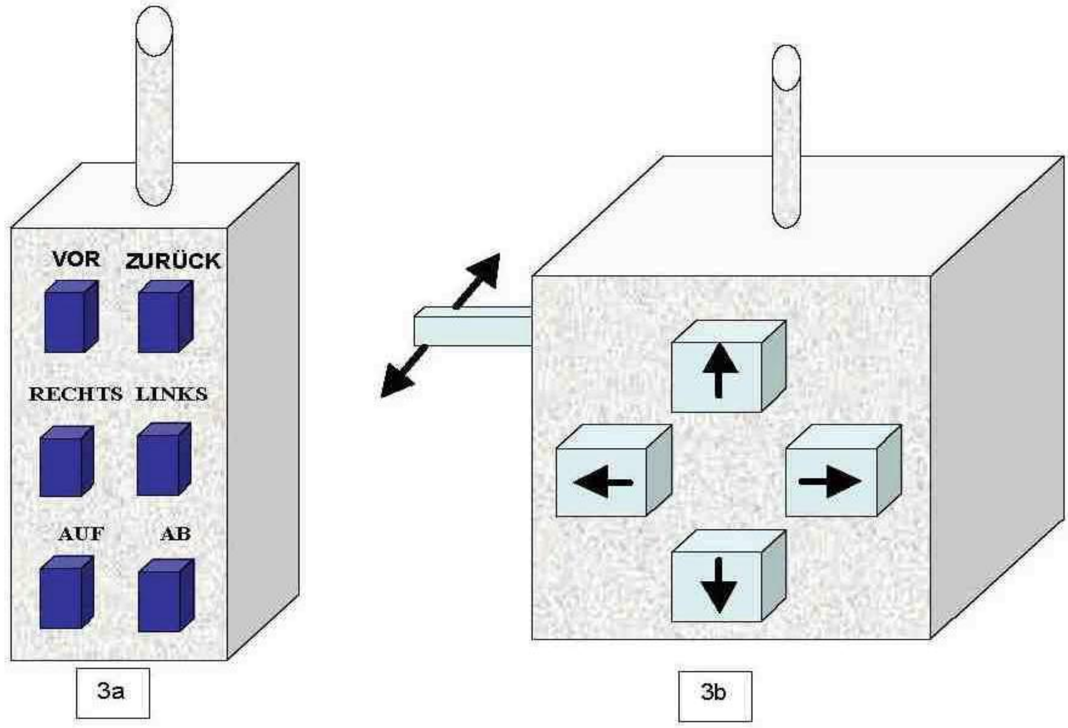
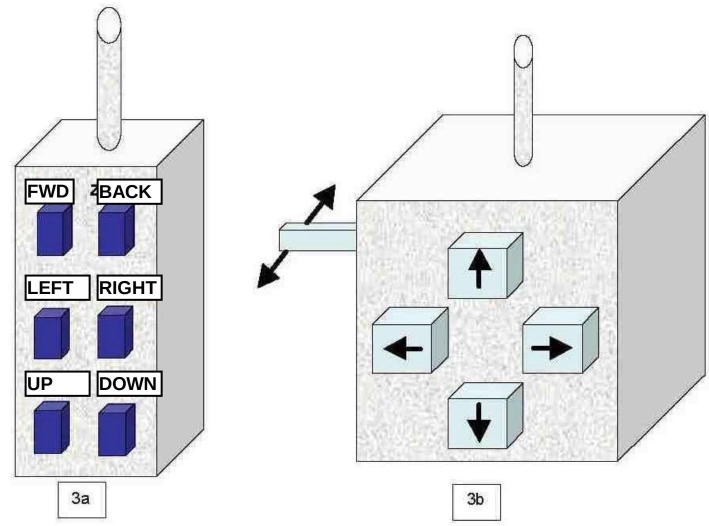


Abbildung 3: nicht erwartungskonforme Schalteranordnung (3a) und erwartungskonforme Schalteranordnung (3b)



No 6 Crane steering interface:
not conform to expectation (3a) – conform to expectation (3b)

Sheet PHYSICAL STRESS:

Last review: 2010-02-10, edited 2011-03-04

BASICS:

Physical stress may determine strain, that can lead to disorders of, among others, the musculoskeletal system and cardiovascular system. The musculoskeletal disorders represent one of the most frequent type of disorders in occupational health. Factors such as size and weight of objects handled, working posture, frequency and duration of manual handling may contribute to activities being hazardous to health.

EXPLANATION :

The following issues should be assessed:

1. manual material handling
2. excessive exertion and impact
3. working posture
4. highly repetitive tasks
5. vibrations
6. individual capacity (see also sheet variability)

Each issue and all possible combinations should be considered as leading to physical strain.

Disorders of the musculoskeletal system can result from awkward and/or forceful manual handling tasks such as lifting, holding, carrying, pushing and pulling. Special attention should be given to handling of heavy loads and/ or at high frequencies [e.g. lumbago, slipped discs]. Additional factors are increased exertion and impact e.g. caused by knocking, hammering, turning, pressing and climbing. Working postures such as sitting, standing, trunk bending, squatting, kneeling, lying and tasks with arms above shoulder height can be critical if the posture is static for longer periods [postural deformities, pain]. The working posture is dependent also on body dimensions; therefore, machinery should be designed in consideration of the expected user population and ideally be adjustable in its dimensions. Highly repetitive tasks (e.g. >30 actions/min for longer periods) [repetitive strain injury] and all forms of vibrations (e.g. hand-arm vibrations, whole-body vibrations) may add to physical strain as well.

Disorders of the musculoskeletal system caused by physical strain are responsible for many difficulties in occupational health. Inadequate design of workplaces can lead to musculoskeletal pain, poor posture, enduring illness and occupational diseases which result in a reduction of productivity and quality.
Please note that physical strain can be influenced by work organization, social and individual aspects but should nevertheless be considered and assessed in the design process.

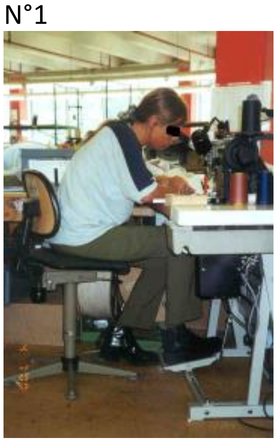
Please note, that there is a link between psychological and physical stress.

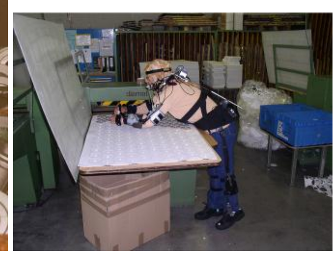
STANDARDS:

EN 1005-1+A1 : 2008 Safety of machinery - Human physical performance - Part 1: Terms and definitions
EN 1005-2+A1 : 2008 Safety of machinery - Human physical performance - Part 2: Manual handling of machinery and component parts of machinery
EN 1005-3+A1 : 2008 Safety of machinery - Human physical performance - Part 3: Recommended force limits for machinery operation
EN 1005-4+A1 : 2008 Safety of machinery - Human physical performance - Part 4: Evaluation of working postures and movements in relation to machinery
EN 1005-5 : 2007 Safety of machinery - Human physical performance - Part 5: Risk assessment for repetitive handling at high frequency

ISO 2631-1 : 1997 Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration - Part 1: General requirements
ISO 2631-2 : 2003 Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration - Part 2: Vibration in buildings (1 Hz to 80 Hz)
ISO 2631-4 : 2001 Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration - Part 4: Guidelines for the evaluation of the effects of vibration and rotational motion on passenger and crew comfort in fixed-guideway transport systems
ISO 2631-5 : 2004 Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration - Part 5: Method for evaluation of vibration containing multiple shocks
EN ISO 7250 : 1997 Basic human body measurements for technological design (ISO 7250:1996) / Note: To be replaced by FprEN ISO 7250-1 (2009-09)
ISO 11226 : 2000 Ergonomics - Evaluation of static working postures Vorgängerdokument
EN ISO 14738 : 2008 Safety of machinery - Anthropometric requirements for the design of workstations at machinery (ISO 14738:2002, including Cor 1:2003 and Cor 2:2005)

EXAMPLES:
N°1



working posture kneeling heavy load & posture highly repetitive & posture

Sheet PSYCHOLOGICAL (MENTAL) STRESS:

Last review: 2010-02-10, edited 2011-03-04

BASICS:

Psychological, or in terms of standards (EN ISO 10075-1), mental stress is the effect of all conditions with a mental impact on an operator, i.e. either cognitive (e.g. information to be processed) or emotional (e.g. potentially aversive consequences of work activities)

EXPLANATION:

- Complexity of task
- Variability of task
- Time constraints on performance
- Cognitive resources required
- Multitasking vs. serial task performance
- Probability of errors
- Consequences of errors
- Adequate design of displays, signals and controls
- Requirements for sustained attention
- Repetitiveness of task performance
- Intensity of workload
- Temporal pattern of workload

Mental (or psychological) stress, defined as the sum of all variables impacting on an operator, will lead to mental strain within the operator, depending on her/his resources, capacities or experience. This strain can lead to positive outcomes, e.g. warming up or learning, or to impairing effects, e.g. fatigue, monotony, reduced vigilance or satiation (see EN ISO 10075-1). The design of the workload must thus aim to achieve an optimal workload or mental stress – not the minimum achievable – in order to avoid any of the impairing effects. E.g., monitoring tasks requiring sustained attention over prolonged periods of time, where the workload may appear to be low, will lead to monotony and reduced vigilance in the operator, with an associated decrease in performance. On the other hand, excessive workload leading to excessive strain, e.g. due to a high complexity and number of decisions, will lead to fatigue, which is also associated with a decrease in performance.

Additional information on design guidelines for the prevention of impairing effects of mental stress can be found in EN ISO 10075-2.

An ergonomic design of tasks, jobs, and machinery – particularly with regard to displays, controls, and the human-machine-dialogue, which has to be adapted to the tasks to be performed – can help to control and optimize mental or psychological stress.

STANDARDS:

For details concerning mental or psychological stress refer to

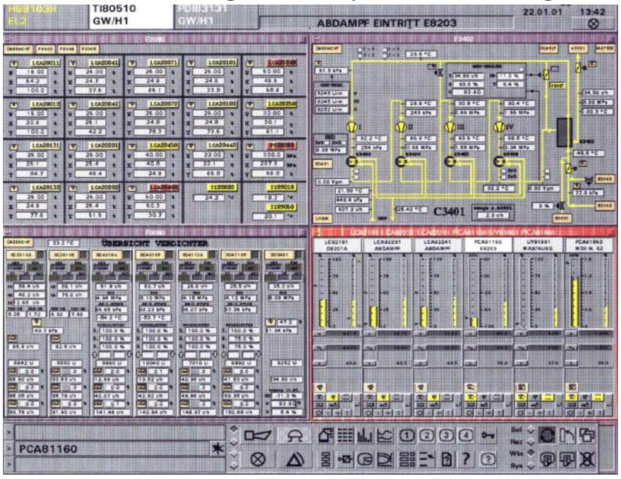
EN ISO 10075-1 : 2000 Ergonomic principles related to mental work-load - Part 1: General terms and definitions (ISO 10075:1991)

EN ISO 10075-2 : 2000 Ergonomic principles related to mental workload - Part 2: Design principles (ISO 10075-2:1996)

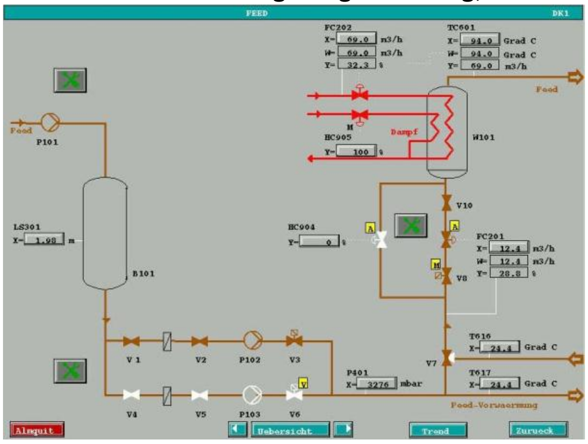
EN ISO 10075-3 : 2004 Ergonomic principles related to mental workload - Part 3: Principles and requirements concerning methods for measuring and assessing mental workload (ISO 10075-3:2004)

EXAMPLES:

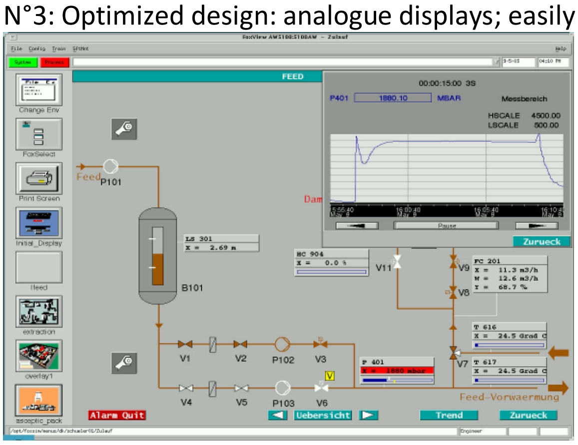
N°1: Bad design: overloaded display; dominant digital coding of information; requires searching for information; coding needs experience; leading to avoidable mental strain in cases of disturbances



N°2: Intermediate design: digital coding; inconsistencies; still leading to avoidable mental stress



N°3: Optimized design: analogue displays; easily accessible dynamic information (trend)



Sheet DISCOMFORT:

Last review: 2010-02-08, edited 2011-03-04

BASICS:

Discomfort refers to a lack of comfort, to a mental or physical uneasiness that is less intense and less localized than pain. At the contrary, **comfort** gives or brings aid, support, satisfaction; comfort refers to a condition furnishing mental or physical ease.

Relevance for designer:

Discomfort like fatigue is a relevant alarming signal, as it may lead to an occupational disease or to an accident and influences performance and quality (§173 principles of safety integration section 1.1.2.(a))

EXPLANATION:

The following issues should be assessed:

1. postural & visual comfort: natural angle of sight, colour, light temperature, physiological angle of comfort
2. interface & contact: shape, temperature, ease, vibrations
3. accessibility & visibility: reaching & visual distances
4. climate/environment: air temperature, wind speed (draught), relative humidity, clothing, caloric/metabolic expenditure
5. highly repetitive tasks
6. olfaction: fumes, odours
7. gustatory (taste): stronger static fields
8. interaction between operators
9. the right balance between activity and inactivity; between vigilance and inattentiveness

Discomfort vs. comfort refers mainly to pressures on the human interface, to segmental postures (intra-articular angles of comfort), to visual issues (natural angle of sight) and to perceptions linked to the environment (such as the thermal comfort, which could be assessed by using two standardised indicia “predicted mean vote” (PMV) & “predicted percentage dissatisfaction” (PPD), see ref. EN ISO 7730)

Discomfort caused by interfaces and environmental factors:

Pressure on the human structures (Pressure in Pascal = force/area (N/m^2): it is generally considered to be an important parameter in comfort evaluation

Working chairs: postural adaptation respecting individual intra-articular comfort (angles and reaching/visual distances) as a result of the activities (tasks), the working environment and the operators’ characteristics.

Thermal comfort is based on the combination of 5 factors (temperature, air flow, relative humidity, clothing and activity)

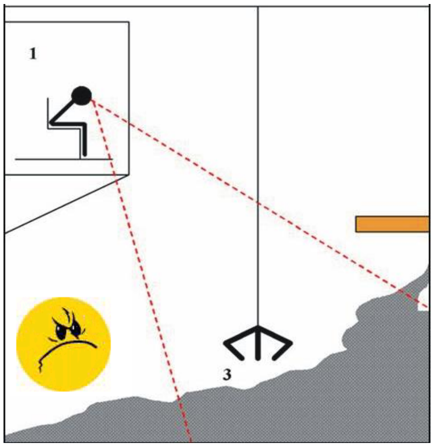
Other factors of discomfort are treated in this same chapter under the sections related to fatigue and stress, and by extension to the mental workload factors

Discomfort appears when nerve endings called “nociceptors” relay to the brain (where signals are treated), via the nervous systems: discomfort/pain caused by signals over an individual specific threshold, no discomfort/pain under this threshold. Specific neurophysiological systems (receptors, nerves, etc.) are involved to treat differentially thermal, acoustic, proprioceptive (position), tactile, visual, olfactive, gustative and pain signals.

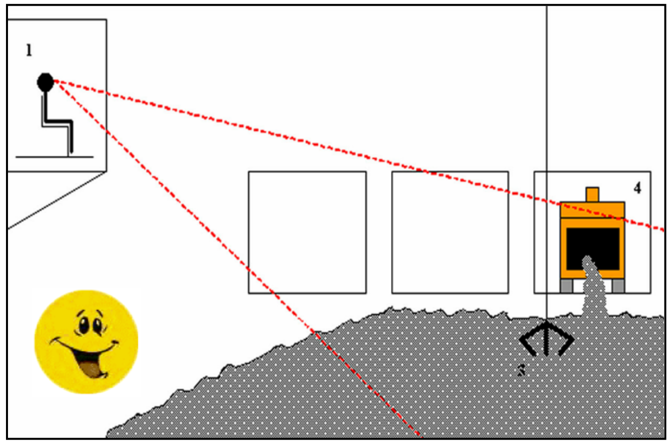
An understanding, e.g., of the pressure patterns (thermal comfort / acoustic / visibility, etc…) that are appropriate for the human being can make machinery usage very satisfying and fulfilling for its operators; it is recognized that an organisation could benefit of a better comfort. At the contrary, discomfort could cause ill-health, absenteeism, decreased productivity both qualitatively (with more discarded items) and quantitatively; more accidents, increased insurance costs and interpersonal conflicts are also related to worse comfort.
STANDARDS: **EN 527-1: 2000** Office furniture - Work tables and desks - Part 1: Dimensions / Note: To be replaced by prEN 527-1 (2008-12). **EN 527-1/AC: 2002** Office furniture - Work tables and desks - Part 1: Dimensions; Amendment AC **EN 527-2: 2002** Office furniture - Work tables and desks - Part 2: Mechanical safety requirements **EN 527-3: 2003** Office furniture - Work tables and desks - Part 3: Methods of test for the determination of the stability and the mechanical strength of the structure **EN 894-1+A1: 2008** Safety of machinery - Ergonomics requirements for the design of displays and control actuators - Part 1: General principles for human interactions with displays and control actuators **EN 894-2+A1: 2008** Safety of machinery - Ergonomics requirements for the design of displays and control actuators - Part 2: Displays **EN 894-3+A1: 2008** Safety of machinery - Ergonomics requirements for the design of displays and control actuators - Part 3: Control actuators **EN 1005-1+A1: 2008** Safety of machinery - Human physical performance - Part 1: Terms and definitions **EN 1005-2+A1: 2008** Safety of machinery - Human physical performance - Part 2: Manual handling of machinery and component parts of machinery **EN 1005-3+A1: 2008** Safety of machinery - Human physical performance - Part 3: Recommended force limits for machinery operation **EN 1005-4+A1: 2008** Safety of machinery - Human physical performance - Part 4: Evaluation of working postures and movements in relation to machinery **EN 1005-5: 2007** Safety of machinery - Human physical performance - Part 5: Risk assessment for repetitive handling at high frequency **EN ISO 6385: 2004** Ergonomic principles in the design of work systems (ISO 6385:2004) **EN ISO 7730: 2005** Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria (ISO 7730:2005) **ISO 7933: 2004** Ergonomics of the thermal environment - Analytical determination and interpretation of heat stress using calculation of the predicted heat strain **EN ISO 8996:2004** Ergonomics of the thermal environment - Determination of metabolic rate (ISO 8996:2004) **EN ISO 9241 Part 1-17** Ergonomic requirements for office work with visual display terminals (VDTs) **EN ISO 9241 Part 20- 910** Ergonomics of human-system interaction **ISO 9920:2007** Ergonomics of the thermal environment - Estimation of thermal insulation and water vapour resistance of a clothing ensemble / Note: Corrected and reprinted in 2008-11-01 **EN ISO 14738: 2008** Safety of machinery - Anthropometric requirements for the design of workstations at machinery (ISO 14738:2002, including Cor 1:2003 and Cor 2:2005)

EXAMPLES:

1) Position and eye-sight of a crane operator in a garbage incineration plant



Bad



Good

2) Example steel grinding at a shipyard

Bad

Good

Sheet FATIGUE: Last review: 2010-02-10, edited 2011-03-04

BASICS:

Proper design will avoid fatigue resulting from the workload impacting on the operator. This can be done by devices allowing the operator to select adapted working parameters (e.g. intensity, speed, frequency) adapting the intensity of the work to the capacities of the (intended) operator population and / or by adapting the temporal pattern of the work stress so that excessive strain is avoided.

Fatigue is a state of impaired performance capacities which results from the consumption of resources due to current or preceding physical and/or mental activities. Fatigue can be physical or mental, general or local. The level of fatigue depends on the intensity, duration and temporal pattern of the preceding activities. Recovery from fatigue requires rest periods with time for recuperation. Fatigue and recovery from fatigue do not follow linear but exponential functions for both intensity and duration.

Fatigue like discomfort is a relevant alarming signal, as it may lead to an occupational disease or to an accident and influences performance and quality (§173 principles of safety integration section 1.1.2.(a))

EXPLANATION:

- Type of workload, e.g. mental or physical, performing calculations, pressing a pedal
- Intensity of the workload, e.g. weight to be moved, complexity of information to be processed
- Repetitiveness of task components
- Keeping work strain at a level that does not lead to an exhaustion of resources by adequate design of the workload or work stress
- you need to consider operators variability including individual capacity (mental and physical)

Fatigue results from activities which deploy more resources than are provided by “natural” recovery. Due to this reduction in resources the following activities will find an impaired state of resources and will thus exploit the resource to an even greater extent. This is why fatigue usually grows in an exponential function. It is therefore necessary to avoid fatigue by proper design of the intensity and temporal pattern of work activities instead of offering extended breaks to compensate extended fatigue.

Indications of fatigue can be

- a greater variation in performance,
- a decline of performance and finally
- a complete breakdown of performance.

If fatigue cannot be recovered from completely by rest, fatigue may build up in the individual and lead to chronic fatigue or even exhaustion. This, in combination with alienation or disengagement from work, can in the long term result in burnout.

Please note that the following issues of fatigue can be influenced by work organization, social and individual aspects but should nevertheless be considered in the design process:

- Temporal pattern of work activities, e.g. duration of uninterrupted work, length of rest periods, time of day (day vs. night work).
- It is thus preferable to avoid fatigue by providing for short work periods followed by short rest periods instead of providing longer rest periods after longer work periods to recover from fatigue.

STANDARDS

For details concerning mental fatigue refer to:

EN ISO 10075-1 : 2000 Ergonomic principles related to mental work-load - Part 1: General terms and definitions (ISO 10075:1991)

EN ISO 10075-2 : 2000 Ergonomic principles related to mental workload - Part 2: Design principles (ISO 10075-2:1996)

For a definition of work fatigue refer to

IS**O 6385 : 2004** Ergonomic principles in the design of work systems

It is important to assess the workload and strain both physical and mental. (e.g. principles and requirements concerning methods for measuring and assessing mental workload are given in

EN ISO 10075-3 : 2004 Ergonomic principles related to mental workload - Part 3: Principles and requirements concerning methods for measuring and assessing mental workload (ISO 10075-3:2004)

EXAMPLES:

Example 1: Intense, repetitive and heavy physical workload

Example 2: Repetitive workload in ergonomical bad position

Example 3: Repetitive workload in ergonomical bad position