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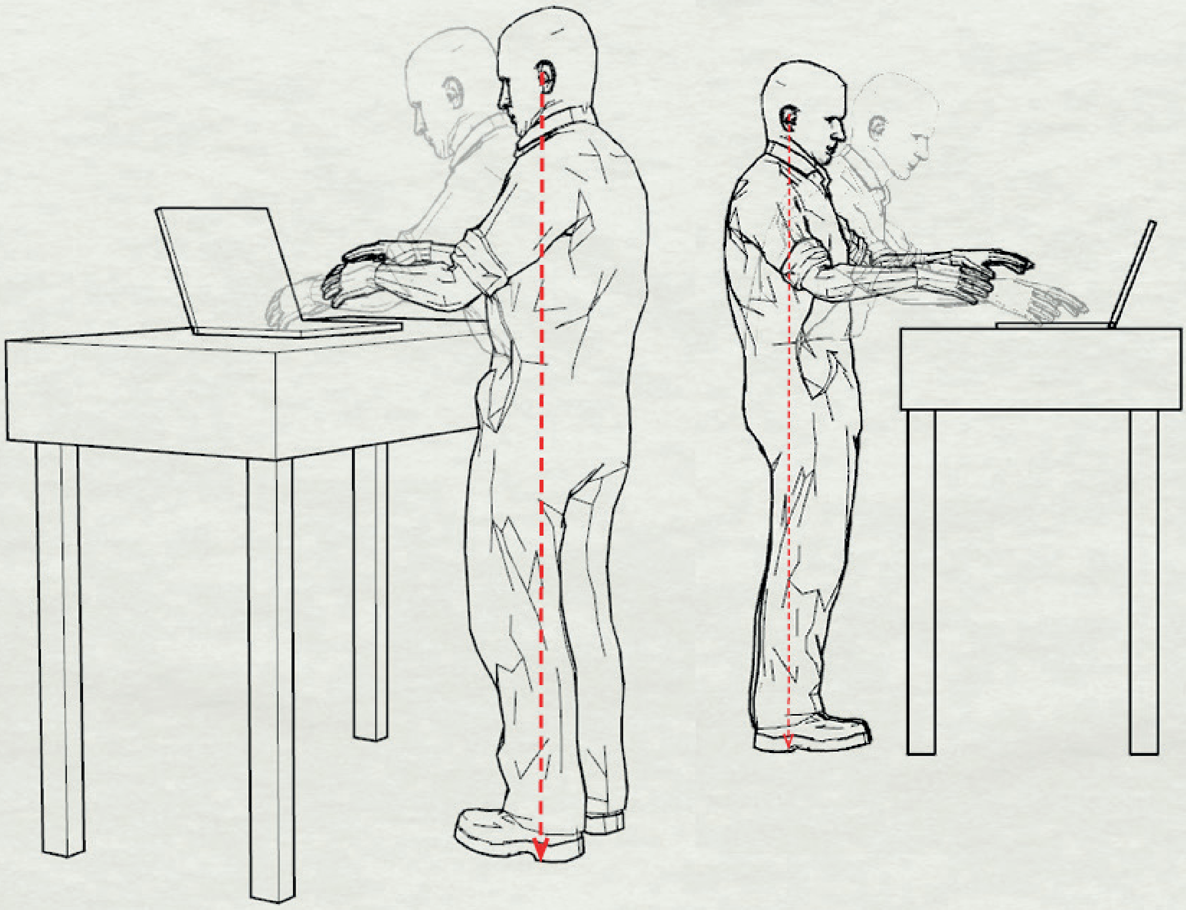
MUSCULOSKELETAL RELIEF PRINCIPLES DERIVING FROM THE EXERCISE, SPORTS AND HUMAN FACTOR SCIENCES

ERGONOMIC WORKPLACE DESIGN



ERGONOMIC WORKPLACE DESIGN

Musculoskeletal relief principles deriving from the exercise, sports and human factor sciences

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TABLE OF CONTENTS

1 INTRODUCTION

For years, musculoskeletal disorders have been responsible for the greatest number of days of work lost in Germany [1, 2]. Pain in the back as well as in the shoulders, neck and arms plays an especially important role here [3, 4]. The development of such conditions often cannot be confined to a single cause, but their prevention can only be successful if the work-related aspect of the cause is reduced [4, 5].

In work-related health problems, the number of days lost to illness is estimated to be 1.6 to 2.2 times higher if they have not been caused by an accident [6]. One preliminary explanation for this is that they develop insidiously over time and therefore their manifestations are more pronounced.

Longer-term health impairments and chronic illnesses increase with age [7]. Given the resulting demographic changes, the significance of such topics as workplace safety and health for labor market policy are going to increase considerably in the future [8, 9].

Ergonomics includes the design of products, product details, workplaces and complex work systems based on criteria determined by human factors and performance preconditions [10]. Ergonomic measures have a particularly high chance of being implemented and indeed accepted when all stakeholders have been informed about their background and can identify with them. Information about and understanding of ergonomic principles are therefore increasingly becoming the focus of ergonomic interventions.

This guide has been commissioned by Ergoswiss AG and has set itself the aim of supplementing current recommendations on ergonomic workplace design with background information emanating from the physiological and exercise sciences to allow the readers to deduce individual measures for themselves.

It is also intended to provide an understanding of frequently occurring work-related disorders of the musculoskeletal system to promote correct organization of the workplace.

In line with DIN EN 614-1 and/or DIN EN ISO 6385, the aim of ergonomics is "[…] to optimize human wellbeing and overall system performance".

2 EFFECT OF THE HEIGHT ADJUSTABILITY OF TABLES ON THE MUSCULOSKELETAL SYSTEM

There is generally no question that a correct adjustment of working height is ergonomically sensible. However, the extent to which working height impacts on the musculoskeletal system cannot be assumed to be general knowledge. For this reason, the body's individual physiological reactions to external stimuli that are associated with stress patterns from everyday working life will be described first of all. This can help deduce an ergonomic arrangement of the worktable.

According to Olivier [13], strain depends on intra-individual preconditions such as physical properties, skills and abilities. Thus, a workplace where parts weighing 10 kg have to be moved about regularly always has the same stress. However, strain is very individual, depending on the strength and stamina of the employee concerned at the workplace.

Figure 1 The same stress (the weight of the box) results in different strain according to the person

2.1 STRESS AND STRAIN

The terms stress and strain were described by Lehmann as long ago as 1953 [11]. Stress is defined as the effect of a force on the body which – depending on the state of health and physical fitness – causes a specific strain [12].

DIN EN ISO 6385 describes the terms as follows:

- Work stress (external work load): "external conditions and demands in a work system which influence a person's physical and/or mental internal load"
- Work strain: "internal response of a worker to being exposed to external work load depending on his/her individual characteristics (e.g. body size, age, capacities, abilities, skills, etc.)"

2.2 ADAPTATION OF THE BODY TO RECURRING STRESS STIMULI

The body's natural response to recurring stimuli that require physical exertion is to build up muscle. This is known not least from exercise training theory. However, the body also adapts to recurring stress stimuli in all other tissues of the musculoskeletal system in order to reduce stress-related overload [14]. For example, adaptations occur in cartilage, bone, connective tissue and tendons on physical activity [15].

2.2.1 Dynamic Stress Stimuli

Adequate recovery times are essential for adaptation processes and these can be timetabled in individually training [14, 16]. The body can also compensate temporarily for high stresses and short-term overload can rapidly be regenerated. However, if the stress is prolonged or highly repetitive, or if it involves a high load, symptoms of overload can occur. Insufficient recovery times impair the regenerative processes and hence stress resistance [14], which can cause musculoskeletal disorders. These can manifest themselves in chronic conditions.
In contrast to sports training, in everyday working life it is not the individual training plan but the work times and activities that govern the alternation of stress and regeneration.

→ Dynamic stress stimuli are generally well compensated for by the musculoskeletal system.
→ High load or constant repetition should be avoided or sufficient recovery time allowed.
→ Recovery processes can be supported by moderate dynamic stress stimuli. Job rotations can thus have a stress-relieving effect.

2.2.2 Static Stress Stimuli

Constant static postural positions generally have an adverse effect on muscles and joints. All the structures of the musculoskeletal system are dependent on the alternation of stress and relief in order to be supplied with sufficient nutrients and be able to break down metabolic products and CO_2 [10, 17, 18]. If this exchange is impaired by persistent static stress, particularly in uncomfortable positions such as overhead working, stress resistance is reduced and can result in muscle and joint complaints [19–21].

→ Static stress stimuli should be avoided where possible.

2.2.3 Insufficient Stress Stimuli

The prolonged absence of stress stimuli on the musculoskeletal system causes degeneration of the musculoskeletal structures and a general reduction in stress resistance [22].
For example, back conditions and slipped discs unrelated to excessive stress on the lumbar vertebral spine occur frequently at office workplaces (cf. Chapter 4 Sitting Correctly). Their occurrence is due much more to reduced activation and an insufficient training status of the stabilizing spinal column muscles.

→ Essential aims of ergonomics are to prevent both overstrain and understrain [23].

2.3 CATEGORIZATION INTO STRESS PATTERNS IN PRODUCTION ACTIVITIES

Work-related stresses to the musculoskeletal system can be divided into repetition-related, posture-related and load-related stresses [20, 24]. Depending on the type of stress, various physical complaints are more likely.

Repetition-related and posture-related stresses in production occur predominantly in highly standardized work processes, such as on the conveyor belt and are characterized by the following properties:

- Frequent repetition of a work process within usually short cycle times
- Usually unilateral physical stresses arise from time- and process-optimized workplace organization
- Partial activities with a high static stress component on individual joints. Thus, with inconveniently arranged workplaces, the shoulders, for example, are required to remain permanently raised to perform the repetitive activity.

- High repetition rate or static posture with low load

Load-induced stresses, on the other hand, are more common at workplaces that cannot be so readily standardized.

→ Ergonomic measures should be undertaken in the order of priority of the TOP principle (technical measures, organizational measures, personal measures). Defined in Germany by section 4 of the German Occupational Health and Safety Act (ArbSchG).

2.3.1 Effects of Frequent Repetitions on the Musculoskeletal System

The internationally employed term “repetitive strain injuries” (RSI) describes conditions that arise as a result of very frequent, low-intensity stimuli. Whereas one single such stimulus does not constitute a high stress because of its weak intensity, RSIs develop from the high repetition of monotonous sequences of movements and insufficient opportunities for regeneration. It is known from sports physiology that insufficient regeneration is considered a cause of muscle and tendon injuries [16].

Injuries can heal better or less well depending on how well a tissue is supplied with blood and how much it is exposed to stress in everyday life. In contrast to muscle, tendon tissue has a weak vascular supply [15] but has to withstand high stresses in daily life. This entails a relatively long regeneration time. Microinjuries at tendon junctions can lead to chronic complaints as a result of minor damage and constant repetitive stress. For this reason, heavily repetitive activities are suspected of being a cause of tennis elbow or tendovaginitis [20, 25].

Because of the low evidence of efficacy of treatments in the area of tennis elbow and carpal tunnel syndrome, stress reduction or ergonomic optimization of the workplace assumes particular importance [26, 27].

As a general rule: prevention is better than treatment [28].

→ Early symptoms should be taken seriously. Depending on the activity and the condition of the tissue, stretches or circulation-promoting measures may be recommended.

→ The position of the joint in repetitive activities has an effect on stress resistance and should be given strict consideration (cf. 2.4.3 Wrist Position and Movements).

2.3.2 Effects of Static Stress on the Musculoskeletal System

For a physiological mode of action, an adequate supply of oxygen and nutrients and the removal of metabolic end products and CO_2, which are produced to an increased extent in the muscle cell on activity, must always remain in balance [29]. However, even with low static stress, the exchange of nutrients in the muscle cell is reduced due to the tension of the active muscle [30].

A frequently described theory of the development of musculoskeletal disorders is the undersupply of muscle or tendon tissue as a result of persistent static tension. In the long term, this results in a high susceptibility to injuries due to a reduction in stress resistance [31, 32]. Venous return is also impaired in static stress. Veins belong to the low-pressure system and their return function is dependent on the alternation of muscle tension and relaxation, known as the “muscle pump” [33]. Compared with static stress, dynamic work can be performed for a very long time without fatigue [10]. In addition, recovery occurs more rapidly after dynamic muscle work than after static [14]. The length of time that a static load can be tolerated depends on the individual’s strength (Figure 2).

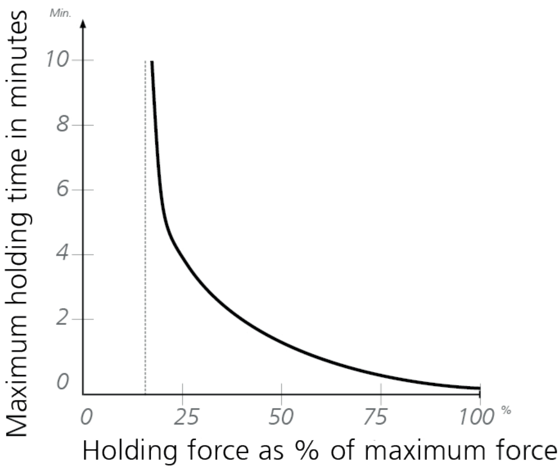

Figure 2 Maximum holding time of fractions of maximum static force, determined on various muscle groups and test subjects (cf. [35]).

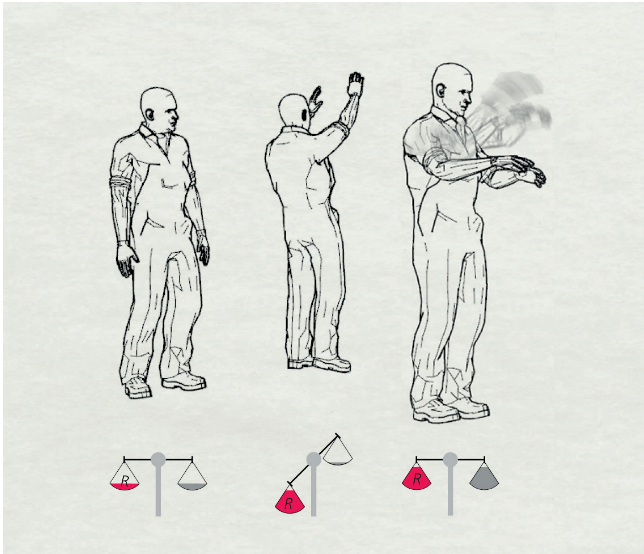

Figure 3 The blood supply requirement (red weighing pan) and the actual supply of nutrients (gray pan) must not get out of balance. In static work (middle picture) the muscle cannot be adequately supplied with nutrients. This can lead to pain. As in a relaxed posture (left picture), so too in dynamic activity equilibrium can be maintained for up to a certain length of time and exertion.

If regeneration is insufficient, an unbalanced relationship of nutrient requirement and removal of metabolic end products can result in tension or muscle hardness, or in further musculoskeletal disorders as a consequence [32]. Even in the range of more than 15% of maximum force, static forces can result in muscle fatigue [10, 35]. This value therefore is regarded as the long-term performance limit for static work [34] and is individually dependent. In contrast to athletes, regeneration time in working life is based not on the individual physiology but on the time demands of production.

2.3.2.1 Constrained Postures

Constrained postures are defined as "adverse physical positions that result in static muscle overstrain" (DIN 33400). Usually these include stresses or activities in kneeling, squatting, lying, bending, or overhead activities (Figure 4). Frequent alternations are even more important for these activities. In the estimation of the Swiss Accident Insurance Institute SUVA, nerves, tissue other than muscles and organs can be overloaded [36].

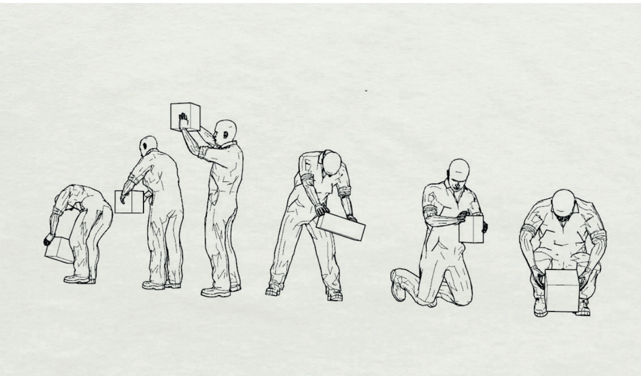

Figure 4 Activities in constrained postures are particularly stressful to the musculoskeletal system

Constrained postures are a common problem. In a representative survey of 20,000 workers in Germany carried out in 2006, more than 14% of workers reported having to work frequently in constrained postures [37].

→ Constrained postures should be avoided as far as possible. Depending on the activity and its spatial environment, all elements of the TOP principle should be considered to avoid constrained postures or reduce their effects.

2.3.2.2 Causes of Imperceptible Static Stress

Whereas a static posture of the shoulders is obvious with overhead activities, many less apparent forms of this muscular holding work are found in everyday areas. Thus, tension in the neck area may be inferred from this provisional explanation if the shoulders are kept imperceptibly but permanently slightly raised throughout the day. At standing workplaces that are inconveniently arranged, a slight forwards inclination of the trunk also causes a subtle static stress on the muscles of the lumbar spine, which in the long run can lead to complaints (cf. Figure 5 and Chapter 2.4.1 Avoid an Inclined Posture of the Upper Body at Standing Workplaces).

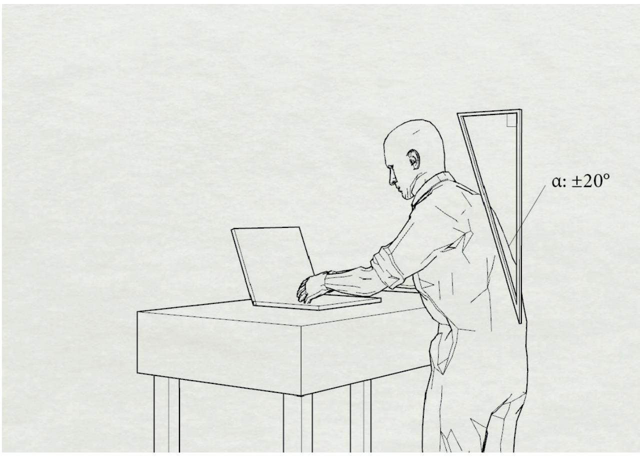

Figure 5 Static tension of the lower back by slight forward inclination of the trunk.

The stress resistance of cartilage is also dependent on a constant alternation of stress and relief. In this case, however, there is a somewhat different underlying mechanism. Joint cartilage is supplied by the fluid available within the joint (synovia). Like a sponge in a water bath, alternation of stress and relief is required here, too, for the cartilage to be sufficiently supplied with its nutrient-rich synovia [22]. In jobs that involve little movement and a lot of standing on the spot, this exchange of nutrients therefore occurs less, despite being needed to an increased extent. The cartilage may be increasingly stressed by this, even though it "only" has to bear its own body weight.

→ To relieve the muscles, static activities should be interrupted as often as possible by dynamic movements. This can be achieved by work organization measures or by conscious active movement exercises.
→ Static positions often occur unnoticed. To reduce the stress, employees should be made aware and workplaces adapted appropriately.
→ To counteract wear and tear effects on the body's joints, workplaces should be designed so that sitting or walking phases alternate regularly with standing.

2.3.3 Effects of Heavy Loads on the Musculoskeletal System

High loads in production occur mainly with less standardized work processes and away from the conveyor belt. Because of high variance and short recovery cycles of the same work steps, technical optimization is not possible or cost-effective for individual process steps. Instead, there are adaptable aids that can be adjusted to meet the corresponding requirements.

The activities at such workplaces – manufacturing may be imagined by way of example – are characterized by the following properties:

- High alternation of handling and processing steps
- Hence a frequent alternation of physical demands
- Handling of sometimes higher loads or in a constrained posture is necessary, as lifting or holding devices are not optimized for the individual process step.

Apart from most areas of automobile production and other sectors that established high ergonomic standards at an early stage, many workplaces can still be found in which high loads have to be handled with a high number of repetitions as well. This can result in load-related back complaints or arm and leg complaints.

The strain on the individual from high loads is dependent on the training status and the frequency with which this stress occurs. If a high load occurs at very irregular and lengthy intervals, only a limited training effect can occur in the musculoskeletal system and the load is perceived each time as just as heavy.
If the stress occurs very often and at short intervals, the risk of overload increases because of insufficient regeneration time. Adaptation of the performance level can be depicted in simplified form by Jankolew's theoretical supercompensation model [38] (Figure 6). Starting from a given performance level, a training stimulus is followed by a recovery phase, which then increases the performance level beyond the baseline value (known as "supercompensation"). Depending on the time of the next training stimulus, the performance level is increased or further reduced from the baseline value. If there is no new training stimulus within the supercompensation cycle, the performance level swings back to the baseline value. The duration of the curve depends on the intensity of the stress and on the individual. For the situation in our example, an interval of about 1-3 days may be assumed between T0 and T3.

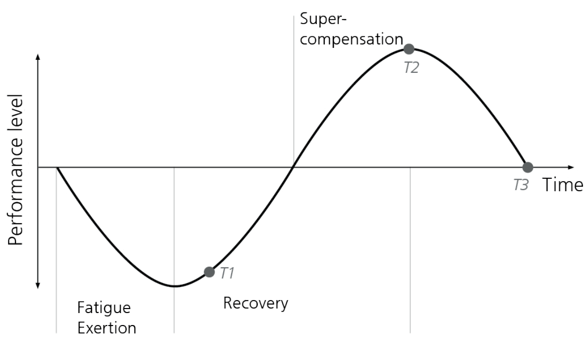

Figure 6 Principle of supercompensation.

T0 A stress stimulus has occurred that results in perceptible fatigue.

T1 If renewed stress occurs during the recovery phase, the original performance level cannot be reached again. → The load is therefore perceived as heavier.

T2 Ideal time for a new stress stimulus. Performance level is higher than the baseline value of T0 → The load is perceived as lighter.

T3 If the stress occurs after supercompensation, there is no difference from the baseline level T0 → The training effect has subsided again and the load is perceived as just as heavy as the first time.

DIN 33411-1, Edition 1982-09
"Physical strengths of man; concepts, interrelations, defining parameters."
DIN 33411-4, Edition 1987-05
"Human physical strength; maximum static action forces (isodynes)"
DIN 33411-5, Edition 1999-11
"Human physical strength - Part 5: maximum static action forces; values"
ISO 11226, Edition 2000 (E)
„Ergonomics - Evaluation of static work postures"
DIN EN 1005-3, Edition 2009-01
"Safety of machinery - Human physical performance - Part 3: Recommended force limits for machinery operation; German version EN 1005:2002+A1:2008"
Din EN ISO 6385, Edition 2004 [updated 10/2014]
"Ergonomic principles in the design of work systems"
Din EN ISO 26800, Edition 2011-11
"Ergonomics - General approach, principles and concepts"

→ Reduction of stress by the use of lighter parts or mechanical aids to take the load.
→ Targeted training measures if high loads are repeated at irregular or fairly long intervals or
→ Active regeneration measures if high loads have to be handled regularly and frequently in the course of the activity.
→ Information about and increased awareness of ergonomic behavior (behavior prevention).

2.4 PRINCIPLES OF THE ERGONOMIC ARRANGEMENT OF THE WORK TABLE

Posture can be evaluated during the activity to establish whether a workplace is ergonomic, As described in Chapter 2.3, the following postural characteristics are regarded as ergonomic:

- No constrained postures (kneeling, bending, squatting, etc.)
- Regular alternation of stress and relief
- Regular alternation of postural patterns

2.4.1 Avoid a Forward Inclined Posture of the Upper Bodyat Standing Workplaces

In the body's confrontation with gravity, the upright posture is defined as a position in which the body segments are ideally aligned against gravity and on top of one another. Observed from the side, the auditory canal, the shoulder girdle and the midline of the leg as far down as the ankle are superimposed on one another in an imaginary plumb line (cf. Figure 7). The upright posture is characterized by economy, minimal energy consumption and efficiency [39].

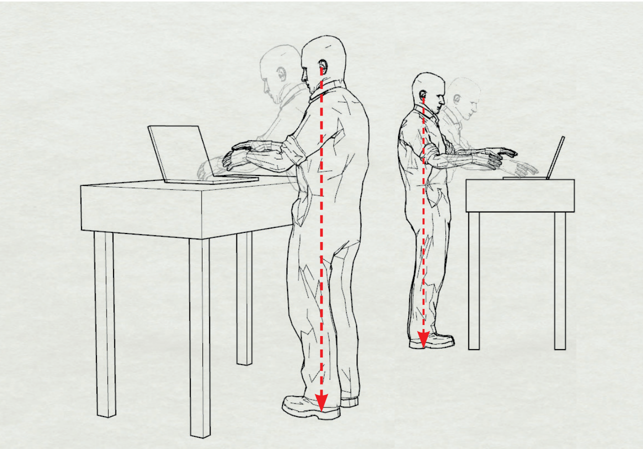

Figure 7 The upright position can be visualized by an imaginary plumb line between the auditory canal and the lateral malleolus.

A forward inclined posture of the upper body, e.g. due to a work table that is too low at a standing workplace, causes static tension of the back extensor. As a result of the tensing of the muscles, the blood-supplying vessels (arteries) are constricted. In the long run, therefore, too low a workplace can predispose to tension, hardening of the muscle, or consequent more serious muscle disorders. Back pain is one of the commonest physical complaints in the population (D, CH) [3, 4].

→ A maximum forward inclination of 20° is recommended. The time factor is unfortunately usually ignored, because even with slight static tension the microcirculation in the muscles is reduced [40, 41].

→ Balancing movements in the form of deliberate overextensions of the back held for a short period (Figure 8) are to be recommended in order to keep passive supporting tissue such as the intervertebral disc in shape [17, 42].

Figure 8 Extension exercise in the standing position. The hands are placed on the sacrum. It should always be ensured that overstretchingdoes not cause any pain.

2.4.2 The Neck

Overextension of the neck should generally be avoided over prolonged periods as this produces increased compression stress on intervertebral disc joints and the nerve roots emerging from them [43]. Furthermore, several authors report that the eyes dry out more rapidly if the screen is placed too high. The reason for this is that the tear fluid evaporates more rapidly as the eyelids are opened wider when looking upwards [44].

If the neck is bent too much, this in turn can cause tension headaches [45].
According to ISO 11226 (Ergonomics – Evaluation of static work postures), an angle range of 0-25° forward inclination is recommended for prolonged postures [41].

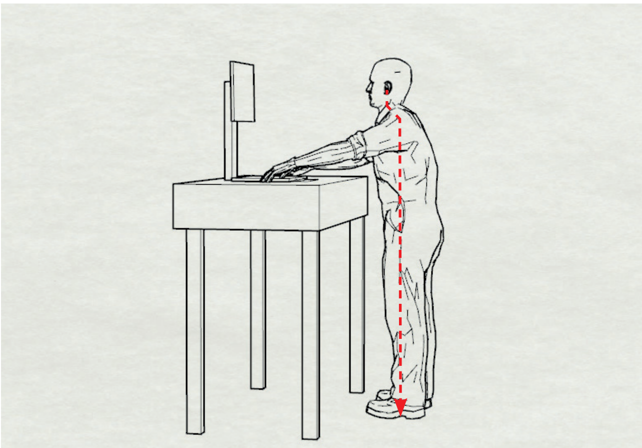

Figure 9 The positioning of the screen has an effect on neck stress. At this workplace the screen is set too high. Intervertebral disc joints and nerves can be stressed as a result. In addition, the shoulders have to be raised excessively.

→ The workplace should be arranged in such a way that neither prolonged nor frequently repeated overstretching of the neck or bending of more than 25° is required to carry out the activity.
→ Screens should therefore not be positioned too high, regardless, of whether the workplace is a seated or standing one. The upper edge of the screen should be positioned about 5 cm below eye level.

2.4.3 Wrist Position and Movements

Disorders such as tendovaginitis and enthesitis, e.g. tennis or golfer's elbow, can result from unilateral, long-term mechanical strain and unusual work of all kinds with inadequate or no adaptation [46]. These conditions are common and prolonged. For example, the mean duration of disease-related absence from work with tennis elbow is 29 days and occurs in up to 30% of all assembly workers [27].

The muscles can best respond to stress if they are in the mid-extension position. External stimuli or minor impulses, which can be caused, for example, by inserting plugs, are less stressful if the wrist is in a neutral position.
Particularly when subject to frequently recurring stimuli or forces, the wrist position plays a crucial role in the development of RSIs [25, 47] (see also 2.3.1 Effects of Frequent Repetitions on the Musculoskeletal System). Attention should therefore be paid to ensuring that the baseline position of the wrist is as neutral as possible, particularly in activities involving a large physical effort and/or large numbers of repetitions.

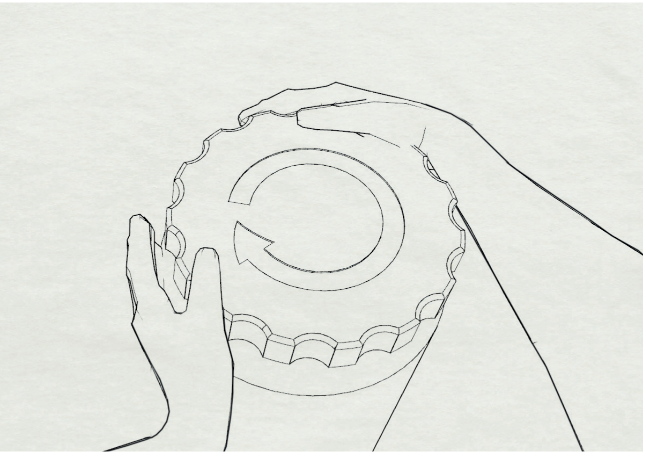

Figure 10 Maximum positions of the wrist should be avoided. The left hand in particular has to be stretched far backwards (dorsal extension).

The EAWS (Ergonomic Assessment Worksheet) sets limits for joint positions beyond which they have a negative effect on the workplace assessment. These are 45° for bending and stretching of the wrist and 15° for lateral angling in the direction of the radius or 20° in the direction of the ulna [48].

- → During the stress and beyond the period of the activity, the wrist positions should be aligned in the neutral position. This corresponds approximately to the position of the hand laid on a computer mouse.
- → The desk height plays a decisive role here and should be adjusted accordingly. If the table is too low, the wrist must be stretched backwards in many activities (dorsal extension).
- → If possible, always rotate the part and do not grip round the part to avoid extreme joint positions.

3 WORKPLACE DESIGN FOR STANDING WORKPLACES

Ergonomically adjustable office furniture and its correct use requires, amongst other things, the necessary knowledge on the part of the user [49]. Various standards give details about workplace design. The information, however, needs to be collated first of all in order to be applied directly.

Collections of body dimensions (such as DIN 33402) serve as a basis for data on workplace design. Three measurements each are usually given for men and women for workplace design, limited to the 5th (only 5% are smaller), 50th and 95th (only 5% are larger) percentiles. The values therefore range from 154 cm (5th percentile of women) to 186 cm (95th percentile of men). Individual measurement data are thus not published. As all height measurements correlate very highly with one another [50], a mathematical extension of these values appears legitimate.

Accordingly, two methods are described for deducing an ergonomic table height.

3.1 DEDUCTION OF DESK HEIGHT FROMPOSTURAL CHARACTERISTICS

Taking into account the determining factors on the musculoskeletal system described in Chapter 2, the following postural characteristics should be given:

- Upright body position (less than 20° forward inclination of the trunk).
- Upper arms should hang down as vertically as possible.
- Neck muscles should where possible not be tensed (at least for prolonged periods).
- Light activity of the abdominal muscles (do not slouch).
- The wrists should predominantly be able to work in the mid-position – particularly when higher demands are made on strength.
- Knees are not fully extended (slight perceptible tension on the front thigh muscles).

3.2 DEDUCTION OF DESK HEIGHT FROM STANDARD SPECIFICATIONS

Table 1 below allows a rapid assessment of the recommended work height as a function of body height and classification of the activity as fine, light, or heavy. Fine activities are defined as activities involving short visual distances and little physical effort. Heavy activities describe work with a high degree of physical effort.

Lastly, however, it is not the height of the tabletop but the working height that is the determining factor. This in turn is dependent on the workpiece to be processed. If this is particularly high, the table height should be corrected downwards.

Table 1 can thus merely offer a guideline value and the characteristics from 3.1 Deduction of Table Height from Postural Characteristics must be constantly rechecked during the activity.

The values are as follows: According to DIN 33406 and ÖNORM A8061 the ergonomic adjustment of table height is based on elbow height and type of activity (fine: elbow height +50 to +100 mm; light: -100 to -150 mm; heavy: -150 to -400 mm). The values for elbow height have been extrapolated by the authors from anthropometric data in DIN 33402 in order to be able to provide individual data for all heights between 1.45 m and 2.10 m. The stated value corresponds in each case to the mid-point of the recommended setting + 2 cm as a correction factor for height as a result of the work shoes worn.

Table 1 Recommended settings for table height according to body size and type of activity.

Height	Fine activity (+/- 2,5 cm)	Light activity (+/- 2,5 cm)	Heavy activity (+/- 12,5 cm)	Height	Fine activity (+/- 2,5 cm)	Light activity (+/- 2,5 cm)	Heavy activity (+/- 12,5 cm)
2,10	1,44	1,24	1,09	**1,77**	1,21	1,01	0,86
2,09	1,43	1,23	1,08	**1,76**	1,20	1,00	0,85
2,08	1,42	1,22	1,07	**1,75**	1,20	1,00	0,85
2,07	1,42	1,22	1,07	**1,74**	1,19	0,99	0,84
2,06	1,41	1,21	1,06	**1,73**	1,18	0,98	0,83
2,05	1,40	1,20	1,05	**1,72**	1,17	0,97	0,82
2,04	1,39	1,19	1,04	**1,71**	1,17	0,97	0,82
2,03	1,39	1,19	1,04	**1,70**	1,16	0,96	0,81
2,02	1,38	1,18	1,03	**1,69**	1,15	0,95	0,80
2,01	1,37	1,17	1,02	**1,68**	1,15	0,95	0,80
2,00	1,37	1,17	1,02	**1,67**	1,14	0,94	0,79
1,99	1,36	1,16	1,01	**1,66**	1,13	0,93	0,78
1,98	1,35	1,15	1,00	**1,65**	1,13	0,93	0,78
1,97	1,35	1,15	1,00	**1,64**	1,12	0,92	0,77
1,96	1,34	1,14	0,99	**1,63**	1,11	0,91	0,76
1,95	1,33	1,13	0,98	**1,62**	1,11	0,91	0,76
1,94	1,33	1,13	0,98	**1,61**	1,10	0,90	0,75
1,93	1,32	1,12	0,97	**1,60**	1,09	0,89	0,74
1,92	1,31	1,11	0,96	**1,59**	1,08	0,88	0,73
1,91	1,31	1,11	0,96	**1,58**	1,08	0,88	0,73
1,90	1,30	1,10	0,95	**1,57**	1,07	0,87	0,72
1,89	1,29	1,09	0,94	**1,56**	1,06	0,86	0,71
1,88	1,28	1,08	0,93	**1,55**	1,06	0,86	0,71
1,87	1,28	1,08	0,93	**1,54**	1,05	0,85	0,70
1,86	1,27	1,07	0,92	**1,53**	1,04	0,84	0,69
1,85	1,26	1,06	0,91	**1,52**	1,04	0,84	0,69
1,84	1,26	1,06	0,91	**1,51**	1,03	0,83	0,68
1,83	1,25	1,05	0,90	**1,50**	1,02	0,82	0,67
1,82	1,24	1,04	0,89	**1,49**	1,02	0,82	0,67
1,81	1,24	1,04	0,89	**1,48**	1,01	0,81	0,66
1,80	1,23	1,03	0,88	**1,47**	1,00	0,80	0,65
1,79	1,22	1,02	0,87	**1,46**	0,99	0,79	0,64
1,78	1,22	1,02	0,87	**1,45**	0,99	0,79	0,64

4 SITTING

4.1 TABLE AND CHAIR HEIGHT AT SEATED WORKPLACES

Essentially, the variables for arranging seated workplaces are described uniformly. However, depending on whether the table height is to be adjusted as well or only the chair height, a different sequence of actions needs to be considered.

4.1.1 Seated Workplace at Which Chair and Table Height Can Be Adapted

1. Adjust chair height to knee level
The uniform recommendation in the literature for chair height is that the angle at the knee joint should be ≥ 90°. The chair height can therefore be deduced from the height of the knee joint gap. This can be adjusted on standing by adjusting the height of the seat pad to the height of the kneecap (Figure 11).

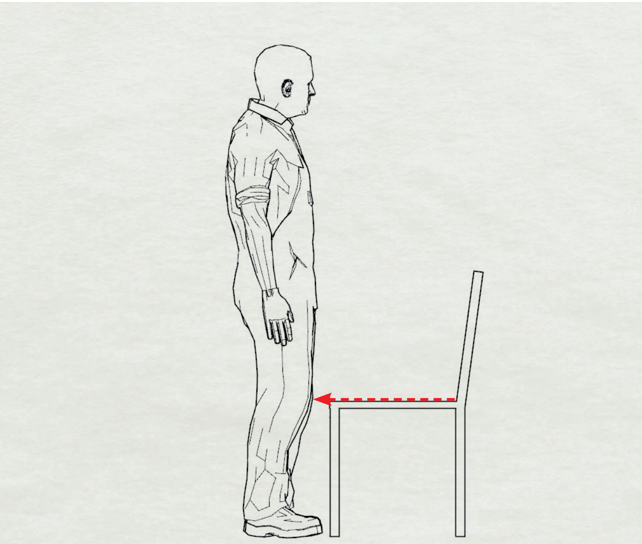

Figure 11 Adjusting chair height. The chair seat should be adjusted to the level of the kneecap on standing.

2. Table height at elbow level
The "elbow rule" is generally recommended for sitting, i.e.: Allow the upper arms to hang loosely and angle the lower arms at 90°. The lower edge of the elbow and the table should now be brought to the same level.

4.1.2 Seated Workplace at Which Only the Chair but not the Table Can Be Adapted

1. Adjust chair height so that the elbows are at the level of the tabletop
The height of the elbows is the recommended yardstick for the table height. If the table height is not adjustable, the chair should be adjusted accordingly.
2. Check angle of the legs and floor contact of the feet
If the feet no longer have sufficient contact with the floor, a foot stool is recommended [44, 51].

4.2 SITTING POSTURE

4.2.1 Contradictions in the Recommendation of ONE Ideal Sitting Posture

The recommendations for the adjustment of the back are equivocal. Sitting upright is given in most guides and standards as the model of correct sitting and recommended for adjusting work furniture. Quite apart from the fact that it is not possible to maintain this model sitting posture over the whole of the working period, there is a further discussion in expert groups as to what is meant by an "ideal" sitting posture [52, 53, 54].
A severely slumped posture is frequently described as the cause of back pain [55]. Equally, there is evidence that a particularly upright posture with the trunk inclined forward increases the stress on the intervertebral discs [49, 56, 57], which can also predispose to the development of back pain [54].

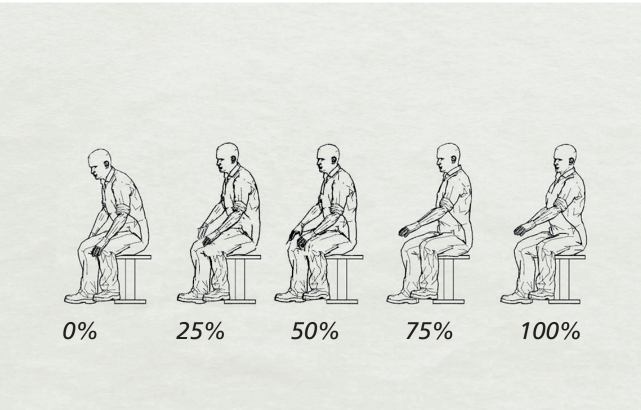

Figure 12 Uprightness of the vertebral column from severely slumped to maximally upright. An upright position of about 75% is recommended [61].

As well as the correct adjustment of seat height, it is increasingly being recognized that a healthy sitting posture is vital [52].
Prolonged sitting in particular is regarded as a risk factor for back pain. Lack of movement has adverse consequences for tissue in the long run [14, 22, 58, 59, 60]:

- An undersupply of nutrients for cartilage and ligaments, which can result in a reduction in stress resistance
- Degeneration of intervertebral discs
- Increasing joint 'stiffness'

4.2.2 Deduction of Sitting Posture from Postural Characteristics

In a survey of physiotherapists, it was generally considered beneficial if the sitting position [54, 61]:

- corresponds to 70 to 75 percent of the maximum upright position of the spinal column
- corresponds to a natural position of the spinal column
- is comfortable and relaxed
- does not place a high strain on the muscles

4.3 SITTING POSTURE

Regardless of which position is considered ideal, it is not advisable to remain immobile in this position over a prolonged period [58]. Movement is needed to keep cells fit and stress resistant. This applies to the back in exactly the same way as to the legs. Reference is frequently made to an "upright-dynamic" sitting posture, which is taught in industrial back schools [49]. The posture of the spinal column can be substantially affected by the position of the pelvis.

Generally the following recommendations may be inferred:

→ A basically positive posture corresponds to 70-75% of the maximum upright position.
→ Nevertheless, do not remain in one particular position – i.e., not even in the "ideal posture".
→ As far as possible, alternate between sitting and standing at the workplace.

5 HANDLING AREAS AND CATEGORIZATION OF WORK TOOLS

Handling areas are defined areas around people, in which objects can be touched, grasped and moved with the hand without any major change of position [62]. The defined handling areas can be helpful for furnishing and arranging workplaces. For example, manual activities requiring a high degree of visual oversight should be performed as close to the body as possible, as the precise movements becomes more difficult with increasing distance from the body. It is also obvious that high loads should not be manipulated away from the body because of the lever effect.

Handling areas are divided in the literature into either three zones (e.g. [10]) or four zones (e.g. [34]). The difference is due to the fact that in some cases the first zone is not described separately [29]:

Zone 1: Working center/assembly site
Both hands work close to one another and are in the center of the field of vision

Zone 2: Extended working center
Both hands reach all points in this zone

Zone 3: One-handed zone
Area for placing items than can be grasped/operated with one hand

Zone 4: Extended one-handed zone
Outermost still usable zone, e.g. for arranging small parts in grab containers. In the case of a large number of repetitions or a high load, stress exerts a deleterious effect on the musculoskeletal system after a short time.

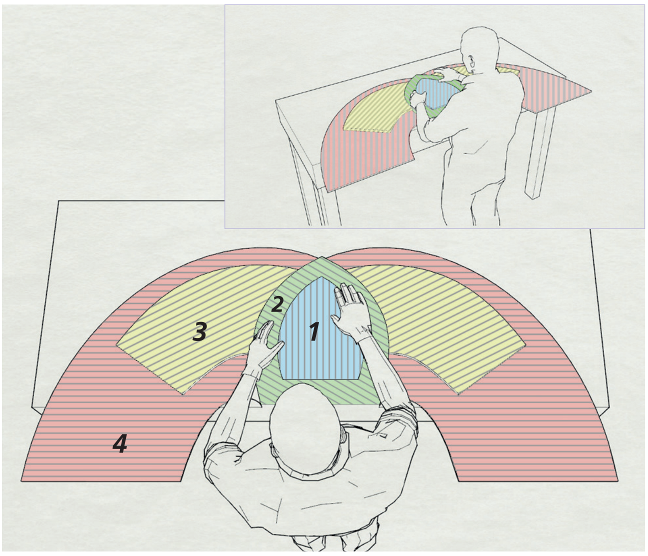

Figure 13 Illustration of handling areas at the workplace

- → Manual activities in the outer areas should be avoided as they require static postural work of the back and arm muscles and the lever ratios are unfavorable. These areas are suitable for the preparation of light materials.
- → If the workplace is used by several employees, it should be arranged for the smallest person, as the handling area of a taller person encompasses the smaller handling area.
- → This can be reduced, for example, by restrictions on movements and must therefore be checked individually.

Further recommendations for designing the work-place are given in **DIN 33402-2 Supplement 1:** 2006-08. A guideline for the use of anthropometric data is given in standard **DIN SPEC 33402-6**.

6 ARTIFICIAL LIGHTING

In additional to the necessary brightness required for work, light also plays a role in wellbeing, because light regulates our "inner clock". Over the course of evolution, a day-night rhythm has developed. Perceived light and hence also lighting at the workplace can have an effect on various physiologic processes. As well as heart rate and temperature regulation, changes in brain activity associated with concentration and vigilance can also be measured [63, 64]. The blue fraction of light, which is processed differently in the nervous system from other wavelengths, is responsible for this [65].

The factors that affect light are [66, 67]:

- Illuminance, lighting height and lighting color
- Luminous flux, luminous intensity, luminance, degree of reflectance, contrast, light yield glare/reflectance, flickering/pulsing of light source, shadows

Minimum values are given in the standards for illuminance below which the level must not fall, but which may be adjusted upwards for the particular situation.

Type of room or activity (examples)	**Minimum illuminance in lux (lx)**	
According to the specifications of:	***DIN EN 12464-1:2003-03***	***German Work Place Regulation ASR A3.4***
Thoroughfare areas and hallways **Break rooms** **Storage rooms**	100	50-150 200 50-300 N/A
Moderately fine assembly work **Coarse/ moderate machine work (Tolerance > 0.1 mm)** **Production facilities requiring permanent manual intervention**	300	300
Tool, gauge and fixture construction **Precision and micromechanics**	1000	 500 – 1500 (e.g. watchmakers)
Offices and office-like workplaces **Writing, reading, data processing** **Technical drawing (drawing by hand)**	500 750	500 750

Table 2 Required lighting intensities (according to DIN EN 124641:2003-03; Section 5.3 and German Workplace Regulation ASR A3.4 Annex 1)

It should also be borne in mind that general visual acuity decreases in old age and glare sensitivity increases [66].

- → Light has a subconscious biological effect on humans, which can impact on concentration capacity and well-being. Possible negative effects from inadequate lighting should not be overlooked in a workplace analysis.
- → As well as the type of activity, age also plays an important role in the choice and arrangement of light.
- → For special visual tasks or those dependent on the employee's visual acuity, additional illumination is recommended for specific areas [67].
- → It is important that the work area is evenly lit and that no glare is produced by high levels of brightness at individual points. This can be avoided, for example, by positioning lights at a sufficient height above the workplace [66].
- → If there are several people at one workplace, the level of illumination must be geared to the person with the lowest light sensitivity of the eyes, i.e., the person who requires the strongest lighting in order to be able to carry out his or her activities properly [10].

DIN SPEC 67600, Edition 2013-04
"Biologically effective illumination - Design guidelines"

DIN SPEC 5031-100, Edition 2009-1
"Optical radiation physics and illuminating engineering - Part 100: Melanopic effects of ocular light on human beings – Quantities, symbols and action spectra"

DIN 5035-8, Edition 2007-07
"Artificial lighting - Part 8: Workplace luminaries - Requirements, recommendations and proofing"

DIN EN 12464-1, Edition 2001-08
"Light and lighting - Lighting of work places - Part 1: Indoor work places; German version EN 12464-1:2011"

ASR A3.4 (not valid for Switzerland), Edition 2011-04
"Lighting"

DIN EN 12665, Edition 2001-09
"Light and lighting - Basic terms and criteria for specifying lighting requirements"

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