
Evaluation of Work Chairs

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1 INTRODUCTION

Recently, changes have been introduced in the manufacture and marketing of work chairs, leading to an widespread use of the concept of "ergonomic quality" of chairs. Nevertheless, this subject once again poses a question: what are the circumstances and requirements based on which a work chair can be truly defined as ergonomic and can these features be identified?

It is well known that technical standards and regulations, however not dissimilar, are in force in different European countries. They define the wide range of manufacturing, dimensional and performance rules of work chairs. Many rules and regulations are still being discussed by European Community Standards Authorities (CEN). Therefore, the literature as well as the regulations have produced a series of criteria, though not as yet uniformly organized. The purpose of this chapter is to illustrate an organized approach for objectively evaluating the ergonomic features of a work chair.

2 BASIC ERGONOMIC REQUIREMENTS FOR WORK CHAIRS

All aspects should be taken into account when carrying out the ergonomic evaluation of work chairs to promote the psychophysical well-being of users. On the basis of this consideration, the following are the principal requirements that a work chair should meet to be defined as ergonomic:

- Safety: the chair should never be the cause or the means of accidents.
- Adaptability: the chair and its components should have dimensions or be adjustable to meet the anthropometric needs of a wide range of users, and of at least 90% of the population.
- Comfort: the chair and its components (i.e. especially the seat and the backrest) should be upholstered, body contoured and reciprocally adjustable so as to meet the physiological needs and characteristics of many different "body shapes, curves and sizes."

- Practicality: the chair and its components should be easy to adjust by the user. The covering materials should favor hygienic conditions.
- Solidity: the chair, its components and adjustment controls should be sturdy, offering good wear and durability without changing performance over time.
- Suitability for the intended use: the chair should be appropriately designed for the intended type of and working environment: a standard chair that fits all types of jobs does not exist.

Each intrinsic factor described here requires the collection of many variables, both qualitative and quantitative, according to which specific criteria were set to determine whether or not a variable is acceptable, and if found acceptable, whether it is optimal or only sufficient.

In particular, reference was made to the criterion that 90% of the users' needs had to be met when evaluating the chair's dimensional and/or adjustment features. To this end, most appropriate, anthropometric parameters were established, and minimum and/or maximum values were set corresponding to the 5th and 95th percentile of the overall population (men and women) distribution. The anthropometric distributions referred to in this study were those of adult western populations as described by Pheasant (1986).

As far as the "shape" of the backrest is concerned, some data collected by the authors were used. These data were obtained by studying a sample of ~350 subjects (men and women) relative to the "shape" of the thoracic and lumbar spine, with the subject standing and sitting.

With regard to safety and performance, reference was made to the European Countries technical regulations in force, particularly German DIN 4551 and Italian UNI 7498.

2.1 SAFETY

When evaluating safety requirements the following characteristics and variables should be checked:

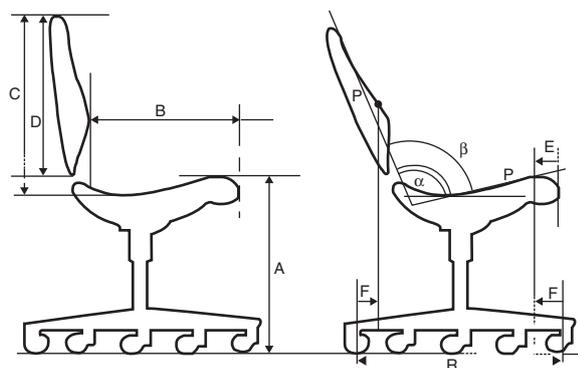
- Stability of the chair: the supporting base in projection should contain the surface area of the seat plane; in particular, the chair-to-ground projection of

vertical force application points, placed 5 cm apart respectively should be contained within the extremity joining the two adjacent spokes. Moreover, the backrest-to-ground projection, with maximum retro-inclination, should fall within the area defined by the supporting base. While taking measurements, castors should be positioned in the most unfavorable position (Figure 1).

- Pressurized gas springs for adjusting the height of the seat plane and the slope of the backrest should be approved and tested by qualified standards authorities.
- Chair adjustment controls, especially if mechanical, should not be activated unintentionally.
- Chair components should be made of non-flammable material, especially the padding, covering materials or a combination of both.
- The chair should come in a choice of castors for different types of floors; it is better to equip chairs with anti-skid castors.
- Absence of sharp edges.
- Armrests should never pinch. In particular, they should not be open at the back.

2.2 ADAPTABILITY

The study of this requirement entails the analysis of a range of dimensional or adjustment variables of the chair components, mostly as a function of the variability of

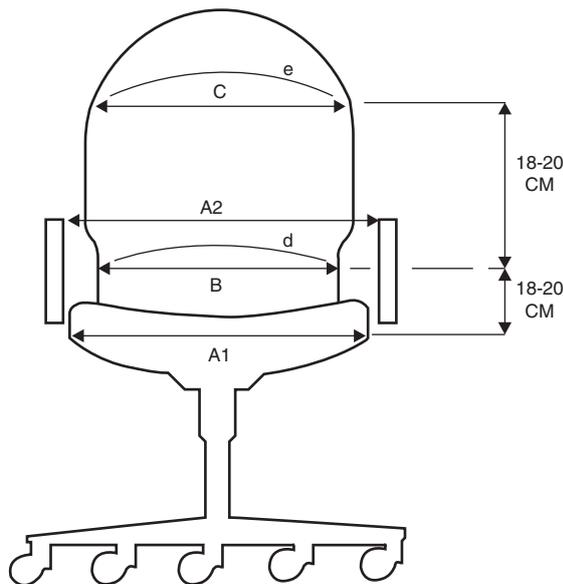


A : SEAT HEIGHT
 B : SEAT DEPTH
 C : BACKREST SEAT PLANE HEIGHT
 D : BACKREST HEIGHT
 E : DISTANCE FROM EDGE OF SEAT TO APPLICATION OF FORCE POINT (5 CM)
 F : DIFFERENCE (IN PROJECTION) BETWEEN SEAT BASE AND UPPER SUPPORTING POINTS
 P : SUPPORTING POINTS
 R : SEAT BASE UNDER LESS FAVORABLE CONDITIONS
 α : NET ANGLE BETWEEN BACKREST AND SEAT PLANE
 β : BACKREST ANGLE

FIGURE 1 Lay-out of some of the measurements used for assessing safety, adjustability and comfort of the work chair (lateral view).

corresponding anthropometric parameters. These parameters include:

- Height of the seat plane (Figure 1): this corresponds to the anthropometric parameter known as “popliteal height.” The height of the seat plane is measured from the ground to the highest point on the front edge of the chair when a weight or compression is placed on the seat plane (e.g. 50 kg). To meet fully the variability of the corresponding anthropometric parameter, this height should be adjustable between 35 cm (=5th percentile in women) and 50 cm (=95th percentile in men). It is surprising to note that current European regulations suggest a minimum height of 42 cm (UNI and DIN regulations): these values correspond to the mean value of the popliteal height of the general European adult population (men plus women). It is worth pointing out that part of the shorter population shall be expected to use a footrest. Therefore, bearing in mind the growth tendency of the popliteal height parameter in the population and the thickness of footwear (2–3 cm), much effort is still needed to lower the minimum height of the seat plane to at least 40 cm. The maximum height of the seat plane should be left unchanged (50 cm) or even increased to 53 cm or more (=95th percentile in men wearing shoes).
- The usable width of the seat plane (Figure 2): this corresponds to the anthropometric parameter “hip breadth” in sitting position. In this case, aside from unrealistic adjustment mechanisms, the first step is to meet the needs of the widest subjects (=95th percentile in women). Once this parameter is set, it becomes easier to meet the needs of other subjects. This parameter, however, becomes even more critical in the case of chairs with armrests. The suggested distance between the armrests should be equal to or greater than 49 cm.
- Depth of the seat plane (Figure 1): this corresponds to the anthropometric parameter “buttock–popliteal length.” It is obtained by measuring the distance between the front edge of the seat plane and the most protruding point on the front of the backrest (i.e. lumbar support). This depth may vary in cases where the backrest is adjustable in depth or merely in slope; conversely it is fixed, with the chairs whose backrest and seat plane are joined into one body. With respect to this parameter, the most important issue is aimed at favoring the 5th percentile subjects of the buttock–popliteal length by considering measurements suitable for the proper placement of the thighs and at the same time supporting the lower back. This is particularly important in chairs without an adjustable depth, where the parameter involved should be <41–42 cm.



A1 : SEAT WIDTH
 A2 : ARMREST CLEARANCE
 B : BACKREST WIDTH (LUMBAR LEVEL)
 C : BACKREST WIDTH (THORACIC LEVEL)
 d : HORIZONTAL LUMBAR CONCAVITY (RADIUS)
 e : HORIZONTAL THORACIC CONCAVITY (RADIUS)

FIGURE 2 Lay-out of some of the measurements used for assessing adjustability and comfort of the work chair (frontal view).

- Backrest height (Figure 1): the backrest is intended to support the trunk. There are different types of backrests. Some chairs come with the backrest and seat plane all in one piece (single body). Other chairs have backrests not adjustable in height, and in other backrest adjustment in height is possible. In the best of cases, the backrest should at least support the trunk starting from the low back curvature (L5–S1) up to maximum thoracic kyphosis. Obviously, the correspondent values of the 95th percentile in men should be taken into account. An acceptable height is capable of supporting at least the entire low back segment. Generally, backrests (whether adjustable or not in height) that support only the low back are defined low. Backrests supporting the trunk up to maximum thoracic kyphosis are considered medium, while those which exceed this height are considered high. In the case of backrests with adjustable height, the backrest should be at least 32 cm high and its upper edge from the seat plane should be adjusted to at least 48 cm from the seat plane. In fixed backrests the “upper edge–seat plane” distance should be at least 48 cm. Backrests with height <32 cm (but >22 cm) are acceptable if the measurements

from the upper edge vary between 37 and 47 cm: support is only provided in the low back segment and, therefore, the chair is not advised for prolonged sitting positions.

- Backrest width (Figure 2): these measurements define minimum widths at the level of maximum lumbar lordosis and maximum thoracic kyphosis. To meet adequately the anthropometric parameters (values corresponding to the 95th percentile in men), these widths should be at least equal to 33 cm in the low back segment and 38 cm in the thoracic segment. For reference, lumbar width is measured by taking the maximum protruding point of lumbar support; thoracic width is measured ~19 cm above this point.
- Height, depth and width of the armrests: armrests are useful for supporting upper limbs while work is not being carried out, for getting into and out of the chair, especially people with functional motor disabilities, and also for keeping balance. On the contrary, armrests are not recommended for tasks involving the use of a high keyboard (especially mechanical), or when a fixed table is used under which the armrests cannot be inserted because the table is too low.

To determine the proper height of the armrest from the seat plane, it is worth recalling the anthropometric parameter “elbow–seat plane height” (obtained by measuring the distance between the elbow-to-ground height and the popliteal height, both taken in sitting position). It is better to refer to the low range of the parameter (small–medium, 5th to 50th percentile).

If the armrest is adjustable in height, its height from the seat plane should range between 15 and 23 cm (variations >23 cm are possible); but if the armrest has a fixed height, it is better to choose a height measuring between 16 and 23 cm.

The recommended depth of the armrest is defined according to the anthropometric parameter known as “elbow-to-wrist length” in the 95th percentile of men. Since this parameter measures ~30 cm and ideally at least two-thirds of the forearm should be properly supported, then the recommended depth for resting the arms should measure at least 20 cm or more, provided that the armrest is located in the right position for this function.

As for the width of the armrest, its dimension should be wide enough to allow for the forearms to be comfortably supported. Armrests with a width of 4 cm or more are recommended.

Table 1 (see end of article) gives a summary of the principal parameters dealt with in this study to assess adaptability. Each parameter was rated optimal, acceptable or unacceptable respectively.

TABLE 1
Main Characteristics for Chair Adjustability

	Optimal (cm)	Acceptable (cm)	Unacceptable (cm)
Seat height		39–52	From 42 to more than 52 Upper height <46 Lower height >45
Seat depth		39–41 Small subj. 42–55 Tall subj.	39–42 for all subjects Fixed <32 or >45
Seat width without armrests		>47	37–46 <37
Seat width + armrests		>49	44–48 <43
Backrest height		>32	23–31 (Short tasks) <22
Adjustable height (low backrests)		Maximum height > 48 from the seat plane	Maximum height 38–47 from the seat plane Maximum height <37 from the seat plane
Backrest width (lumbar region)		>33	29–32 <28
Armrest: height, depth, width		16–23, 25 ± 5, >4	24–25, 16–19, 2.5–3.5 >26 <15, > 31 <15, <2.5

2.3 COMFORT

With respect to the other requirements, comfort is certainly the most difficult to assess from an analytical standpoint. The idea of comfort is easily influenced by the subjective evaluations of the users, and in literature this subject is still being widely discussed. The following reflections can shed some new light on the basic approach to the problem.

A work chair should always come equipped with a backrest to support the trunk. A backrest permits the relaxation of paravertebral muscles, and leads to less pressure overloading the intervertebral disks as compared with chairs without a backrest, even when these kinds of chairs come with a forward sloping seat plane.

A backrest also allows the trunk to alternate periods of support with periods of no support, thereby obtaining a variation in pressure load (otherwise impossible to achieve without a backrest), which is essential to the good nourishing mechanism of intervertebral disks.

A forward sloping seat plane, which is useful only in a limited number of workplaces with specific needs (i.e. work carried out at a drawing table), may indeed contribute to maintaining the physiological curvature of the lumbar lordosis, but nonetheless it tends to overload the lower limbs, particularly the knees. In cases of extreme seat plane inclination, a knee block has compensated for this overloading, but this solution is the cause of another problem, i.e. menisci disorders.

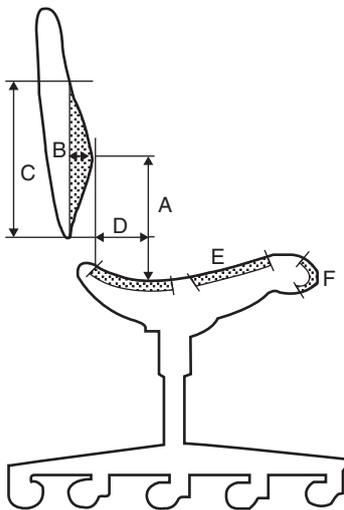
Proper support of the lower back is achieved using a sufficiently reclinable backrest with respect of a correct profile of the lumbar lordosis. Both conditions are vital to reducing muscle and articular overloading of the spine.

Therefore, in terms of comfort, a clear choice was made in favor of chairs with backrests reclinable, autonomous from seat plane, suitably contoured with a lumbar support and ideally adjustable in height and with a slightly retro-inclined seat plane. The backrest and the seat plane should

also be shaped according to the details described in this paper. It is now possible to give the analytical details of each aspect characterizing a chair's comfort.

- Inclusion of the backrest (Figure 1): its adjustability is aimed to meet the needs of different people, both subjectively and task-related, bearing in mind the relationship with the overall layout of the workplace. Too much inclination tends to interfere with work tasks and it may be the cause of a man/chair imbalance with respect to the supporting base. Inclinations of <90° with respect to the horizontal plane is ineffective for supporting the trunk. The possibility of varying the angle between the trunk and the thigh, obtained by adjusting the inclination of the backrest, is also useful during different work tasks. From this standpoint, a good synchronous balance mechanism of this opening depending on the inclination angle presents an advantage, but it is not a necessary condition. Hence, backrests equipped with an inclination ranging between 90 and 115° (with respect to the horizontal plane) are preferable (120° for high backrests). The backrest should be adjustable to the desired inclination for whatever position or range of inclinations (i.e. almost 5°). The net angle between the backrest and the seat plane should be less than these values depending on the slight retro-inclination of the seat plane or the presence of synchronous opening devices between the backrest and seat plane. As for comfort, the chairs with a backrest, albeit reclinable, that is one piece with the seat plane (single body) are less effective. Likewise, in the absence of blocking devices for desired inclinations, backrests with inclinations obtained only by putting pressure on them (even with adjustable resistance) are less advisable.

- Contours of the seat plane (Figure 3): to avoid compressing the neurovascular structures at the popliteal level, the front edge of the seat should be rounded and possibly made of non-rigid material. The correspondent curvature should have a radius contained within 4–12 cm, and the height of the rounded area should measure ~4 cm. From front to back, the seat plane should be sloped slightly backwards in order to favor the placement of the thighs and stop the buttocks from sliding forward. A slope ranging between 3 and 10° respect to the horizontal plane with the seat in normal position is recommended. These values may be slightly increased if synchronous opening devices of the seat plane — backrest angle are present. Towards the back of the seat plane, a concavity should be designed for housing the buttocks. The center of this concavity, from back to front, should be placed within 10 cm of the most protruding point of the lumbar support with the backrest in vertical position.
- Lumbar support (Figure 3): with regard to this basic element, the height of maximum protrusion from the seat plane, the depth and the length of its extension along the backrest should be taken into consideration. The height of maximum protrusion can be defined by considering the anthropometric parameter “lumbar lordosis–seat plane height.”



A: LUMBAR SUPPORT HEIGHT (FROM SEAT PLANE)
 B: DEPTH OF LUMBAR SUPPORT
 C: EXTENSION OF LUMBAR SUPPORT ALONG BACKREST
 D: SPACE FOR BUTTOCKS (FROM BACKREST)
 E: SEAT PLANE AREA FOR MEASURING INCLINATION
 VS. HORIZONTAL
 F: ROUNDED FRONT EDGE

FIGURE 3 Lay-out of some of the measurements used for assessing comfort of the work chair (lateral view).

In optimum cases, this height should be adjustable between 17 and 28 cm. In cases of chairs where the backrest is not adjustable in height, maximum protrusion is fixed between 20 and 24 cm from the seat plane. The depth of the lumbar support at maximum protrusion should be set according to data in literature and original data on the anthropometry of low back curvature. To meet anthropometric requirements and different postural choices, depth should be adjustable between 2 and 5 cm. If it is not adjustable, then the depth should be set between 2 and 4 cm. The length of lumbar support extension along the low-back padded area of the backrest is determined by using such anthropometric parameters as: “distance between 1° sacral vertebra and 1° lumbar vertebra” and “distance between 1° sacral and maximum thoracic kyphosis.” Generally speaking, extension ranging between 20 and 30 cm are suggested for medium-sized backrests and 13–16 cm for low ones. As for vertical contour of the backrest padding, it is important to notice that in the case of medium or tall backrests the curvature between the 1° sacral vertebra and the maximum thoracic kyphosis is not symmetric with respect to maximum lumbar lordosis, but rather is somewhat slight on top and more accentuated at the bottom.

- Padding: the aim of a good seat plane and backrest conformation, as well as eventually the contours of the padding, is to establish the right interface between the user’s body and the seat itself, avoiding the undesirable effects of compressing any protruding bones and providing an appropriate distribution of body pressure. For most office workplaces, chairs should be manufactured using semi-rigid upholstery (with a deformation due to the weight of a person <2.0–2.5 cm), sufficiently thick (4–5 cm) and preferably applied onto a well-shaped body of the chair. In industrial environments, where chairs often come in contact with dust and liquids, it would be inappropriate to use padded and/or upholstered chairs. Therefore, other kinds of materials are preferred (i.e. wood). In this case, a good profiling of the seat plane and backrest is highly recommended.
- Covering materials: the surface that comes in contact with the user should not create any thermal undesirable sensation. In particular, these materials should allow the skin to breathe but avoid creating cold sensations. Therefore, the suggested covering materials for seats and backrests should be made of porous material (placed over the padding) or in wood, whereas plastic, rubber and metal chair covers are not recommended. The armrests should be covered with plastic or padded material to avoid creating undesirable thermal sensations or hitting

the nerve structures of the elbow on rigid parts of the chair. The covering material, particularly of the seat plane, should be rough enough to counter the buttock's tendency to slip forward.

Table 2 (see end of article) gives a summary of the principal parameters dealt with in this study to assess comfort. Each parameter was rated optimum, acceptable or unacceptable respectively.

2.4 PRACTICALITY

Adjusting the various chair components should be made as easy as possible for the user. If adjustments have to be made using controls that are difficult to maneuver or hard to reach, ultimately they will never be used.

The adjustment controls, particularly of the seat height and the different functions of the backrest, should be easy to reach from a seated or semi-seated position, without the need for use of force or additional equipment. Any knobs or handles should not be easily removable, and, if necessary, they should be fitted with guide stops.

The covering material of the chair should also be washable in order to guarantee the minimum hygienic requirements. This aspect is particularly important in industrial or in very dirty environments, or in cases where the chair is intended for multiple users. In these cases, the chair can be

covered in fabric protected with easily removable covers or made of wood.

2.5 SOLIDITY

Resistance to wear of the chair and its components is a prerequisite not only from a marketing standpoint, but also for ensuring the durability of ergonomic performance.

The sturdiness and resistance to wear of the seat and its components can be evaluated using the specific tests and interpretation criteria developed by National Standards Authorities, with validity in each of the countries respectively. Therefore, the results of such tests are important for making an overall ergonomic evaluation of a chair. The type of warranty and customer assistance provided by the manufacturer or distribution organization is another important aspect of this evaluation.

2.6 SUITABILITY FOR THE WORKPLACE AND INTENDED USE

As mentioned earlier, every workplace has its peculiarities and special needs from an ergonomic standpoint.

The chair is a separate working instrument and, therefore, it can have different characteristics and features that make it suitable (or unsuitable) for certain job settings, work environments or potential users. In other words, on the basis

**TABLE 2
Main Characteristics for Chair Comfort**

	Optimal	Acceptable	Unacceptable
Buttock max concavity (from backrest)	<10 cm	>10 cm	Not padded
Rounded front edge (radius)	4-12 cm	<3 cm	flat seat plane
Seat plane angle (degrees)	3-10°	0-2° 11-14	None Fixed forward or fixed backward >15°
Lumbar support			
*Height from seat plane	17-28 (adj.) cm	20-24 (fix.) cm	None
*Depth	2-5 cm	>2 cm	
Backrest angle			
*Net angle	90-110°	90-110°	
*Angle vs. horiz.	90-120°	90-105°	Fixed <90° or >110°
Horizontal profile (radius)	40-80 cm	30-40 cm >80 cm	Not upholstered flat backrest
Padding		Semi-rigid	
Covering materials		Nonslip and that allow the body to breathe	
Armrest upholstery		Plastic or padded	

of a few characteristics, it is possible to define the general areas of potential chair use.

The "intrinsic" characteristics orientating the chair towards a specific job destination were examined in this study; then a summary is presented of all the necessary characteristics of chairs intended for wide areas of utilization.

- Castors: they should be buffed according to the type of floor used (smooth, carpeting, etc.). Chairs with castors for carpeting should not be used on smooth surfaces.
- Armrests: sometimes compatibility problems arise between the height (lower edge) of the worktable and the armrests.
- Covering materials and padding: in chairs intended for use in crowded areas, or areas with flames and sparks, both materials should be flameproof. In workplaces involving prolonged seated positions, a chair with semi-rigid padding is preferred. In working environments where the seat is easily dirtied, washable chair covers or upholstery should be used.
- Characteristics of the backrest: low, single body and non-adjustable backrests are not recommended

for jobs involving prolonged seated positions. For these kinds of jobs, medium-to-high backrests that are separate from the seat plane are suggested; backrest should be adjustable almost in inclination and fixable in the chosen position.

With regard to VDT workstations, it is worth recalling that EEC Directive no. 270/90 establishes that seat plane should be adjustable in height and backrests should be adjustable in inclination and in height.

For jobs involving prolonged seated positions, it is worth stressing that medium-to-high backrests with both kinds of adjustability and proper backrest profiling, especially in the low back area, are preferable. Chairs with low backrests should be restricted to jobs that do not entail prolonged sitting positions, provided they come equipped with the same two adjustments for the backrest.

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