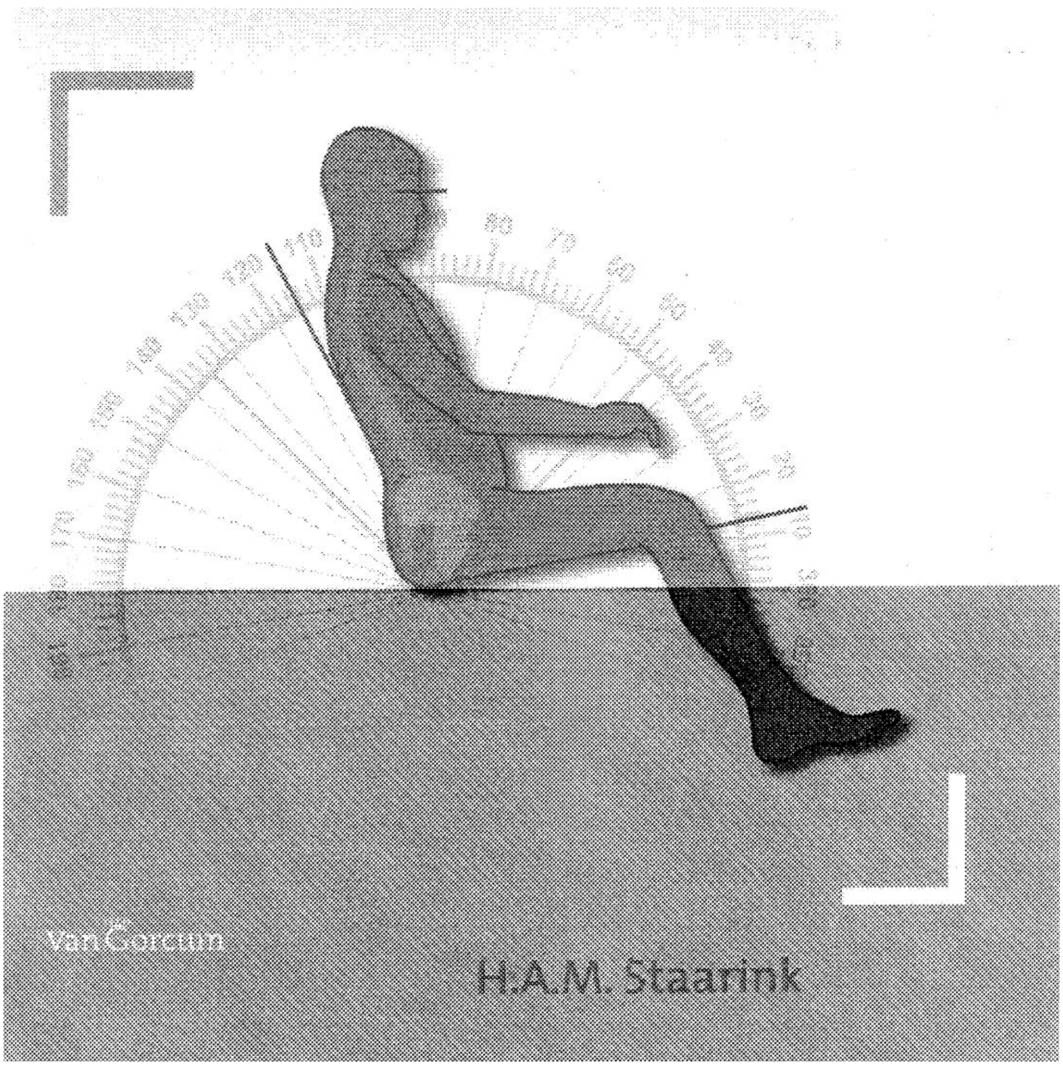
All there is to know about sitting

sitting behaviour, seats and wheelchairs



All there is to know about sitting

Over sitting behaviour, seats and wheelchairs

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0.0 About this book

This book has two sections.
In the first section sitting behaviour is observed, analysed and explained in a narrative form. Then conclusions are drawn from this and the consequences summed up for sound sitting behaviour and the desired properties for various sorts of seats and furniture, with special attention being given to seating support in wheelchairs. The text is supported wherever possible with illustrative diagrams, drawings and photographs. Each chapter ends with a summary and conclusions.
The second section consists of an in-depth study of four separate subjects that are presented as such. The approach and the language used are concise and of a scientific nature. Where necessary, tables, graphs and overviews.

This book is the result of many years of involvement with the phenomenon sitting and especially of the desire to comprehend it. That this book had to follow earlier publications is the result of enlightening furtherance of that comprehension gained from the author's own research carried out between 1997 and 2000 together with J. van Wijngaarden, G.P., and A. Tournier, physiotherapist and manual therapist.
Confirmation of the results obtained during the author's own research was, to an important extent, to be found in the 1969 conference proceedings *Sitting Posture* edited by E. Grandjean. Research results obtained by Grandjean and Wotzka proved to give the same results as the author's own research when the definition of a sitting posture that he had developed was applied, but could now be fully explained and understood. In writing and compiling this book, the following publications by the author were used:

- *Het zitboek, zithoudingsproblematiek in rolstoelen,* 1994 – An analysis of the problems with sitting postures in wheelchairs.
- *Sitting posture, comfort and pressure, assessing the quality of wheelchair cushions,* 1995, PhD thesis - here referred to as 'the cushion research'.
- *De Kunst van het zitten,* 1999 – The Art of Sitting – a popular discourse on sitting.
- *Handboek Dwarslaesie Revalidatie,* 2nd edition 2007, editor: dr. F. van Asbeck, ch. 18.1.1.1, Biomechanical and (neuro)physiological backgrounds of sitting.

Furthermore, in 2001 work started on a project, *SMS* (Sit Measurement System) assigned by P.R. Sella in Oldenzaal, the Netherlands, to use analysis software to render pressure measurement results clearly understandable for therapists. In this project, the approach that was used in *Sitting posture, comfort and pressure* has been developed further for application on an individual basis.
In 2006, the SMS project was partly instrumental in bringing P.R. Sella and the rehabilitation centre Het Roessingh in Enschede, the Netherlands, together in the *Pilot Project SMS Seating Advice*. This project aims at evaluation of the new insights into sitting in wheelchairs and their implementation in Het Roessingh. This initiative is described in the fourth chapter of the second section.
The aim of this book is to show and to prove that clearly defined conclusions and consequences can be drawn from an understanding of sitting behaviour, and that a sound sitting posture is less individual than most people now assume.
Hence the title: ***All there is to know about sitting.***

Part A

Observation, explanation and application

1.0 Observations on sitting behaviour

This chapter describes sitting behaviour . What are the most noticeable characteristics of sitting behaviour and how is this related to the furniture?
There must be causes underlying this behaviour. If the causes can be understood, then it must be possible to draw conclusions from them and to infer consequences for advisable sitting behaviour and well designed furniture.
But first: observation.

1.1 Sitting behaviour

When people sit, they never sit still. They continually change position. Sometimes this is barely perceptible, and sometimes they clearly shift their posture. This depends on what they are doing and the earnestness with which they are doing it: eating a sandwich or having a conversation, drawing or using a computer. The relaxed direction of gaze that is needed for these activities is definitive for the posture that is adopted.
For any one direction of gaze a great variation of postures can be observed. The posture afforded by the chair in use is of very little consequence. The posture adopted is frequently totally different from the posture intended by the designer of the chair.

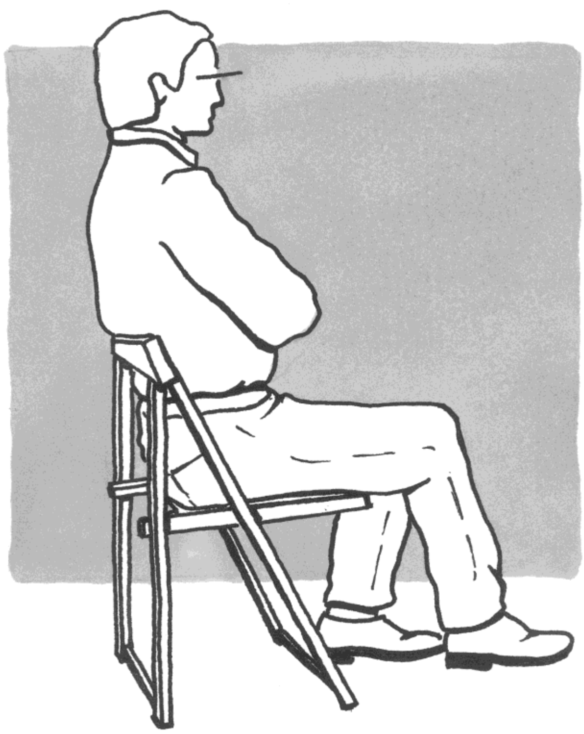

Figure 1-1: An upright, active posture on a dining room chair.

The chair seen in figure 1-1 presupposes active use and an upright, active posture. However, as soon as a conversation starts, a more relaxed position is quickly sought: the buttocks move slightly forwards on the seat and the person leans back and supports their/his trunk on the higher part of the backrest. Look at the person in figure 1-2. Apparently this posture is more comfortable than the previous active posture. In actual fact, it looks a lot less comfortable.

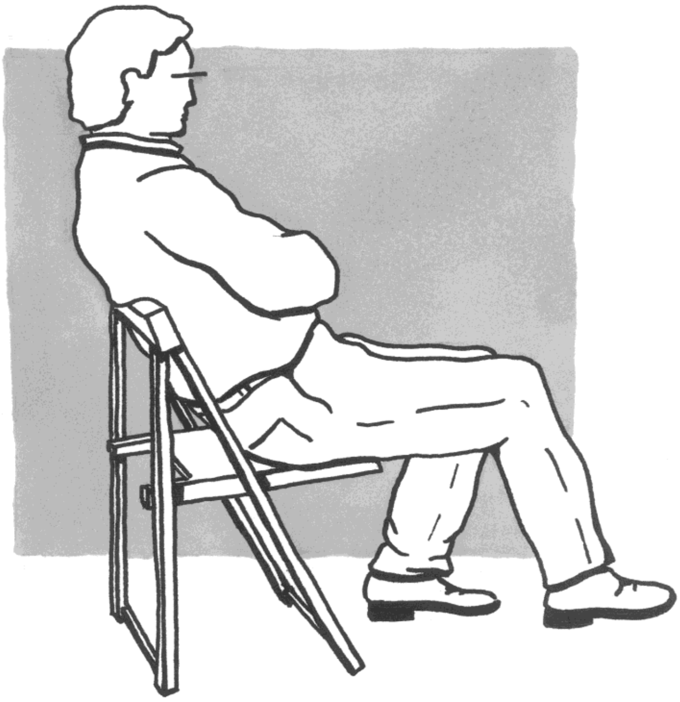

Figure 1-2: A relaxed posture in a chair that affords an upright, active posture.

The person looks as if he is about to slide off of the chair and the hard wooden backrest must be a localized cause of great discomfort for his back. And yet, for the time being, this is the chosen posture. After a while, however, a new posture will be adopted – consciously or unconsciously – because of the discomfort. One characteristic of this sort of posture is the fact that they demand very little energy to maintain. Clearly people find this agreeable.
People are continually trying to find postures that, at least initially, give a direct feeling of comfort. If, after a while, it proves to be something less than comfortable, then the posture is changed for a different posture that, again, is initially experienced as comfortable. Clearly, people are not able to choose a posture that is comfortable for a longer period of time, or the seating support is not adequate to afford that comfort for long periods, or both.
Sitting behaviour is apparently determined by a perception of comfort at a given moment: the momentary perception of comfort.

The same process can be observed in people who are watching television from a sofa. The sofa is, of course, well provided with cushions. The people are sitting or lying comfortably looking at the television. But this status is not maintained for long. Even in this comfortable situation the need will soon arise to change posture. This usually happens unconsciously. The body gives the prompts: it feels discomfort somewhere and needs to alleviate this. It is this same mechanism that causes us to turn from one side onto the other in our sleep. Apparently all of those soft cushions and the posture that they lead to are not sufficient for us to watch television ‘undisturbed’ for long periods.

A remarkable situation can be observed in the case of driving a vehicle. The driver steers from a fairly fixed posture and proves capable of maintaining this situation for hours at a time. Professional drivers are on the road for more than 8 hours a day with only short breaks between times. If the driver complains about his seat he is either given a 'special' seat or his seat is 'adapted'. What exactly has been changed is often hardly identifiable, but it seems to work. There is every reason to follow this present book with research into this phenomenon of being able to drive for long periods and to find an explanation for it.

Figure 1-3: A posture that can be maintained for long periods whilst driving.

Another interesting observation is the posture and sitting behaviour of people using a PC. The posture is very obviously affected by the placement of the screen as this, of course, determines the line of gaze. A screen that is set high dictates an upright, active posture. Often you see people actively sitting on the edge of their chair without making any use of the backrest. In contrast, when they use the telephone they seek out a relaxed posture with the aid of the backrest.

If the screen is placed too low, then the gaze is directed downwards, the back arches and the person hangs, as it were, in their own back. This posture certainly requires very little energy but it causes a great deal of strain on the back. The head has to be lifted more and

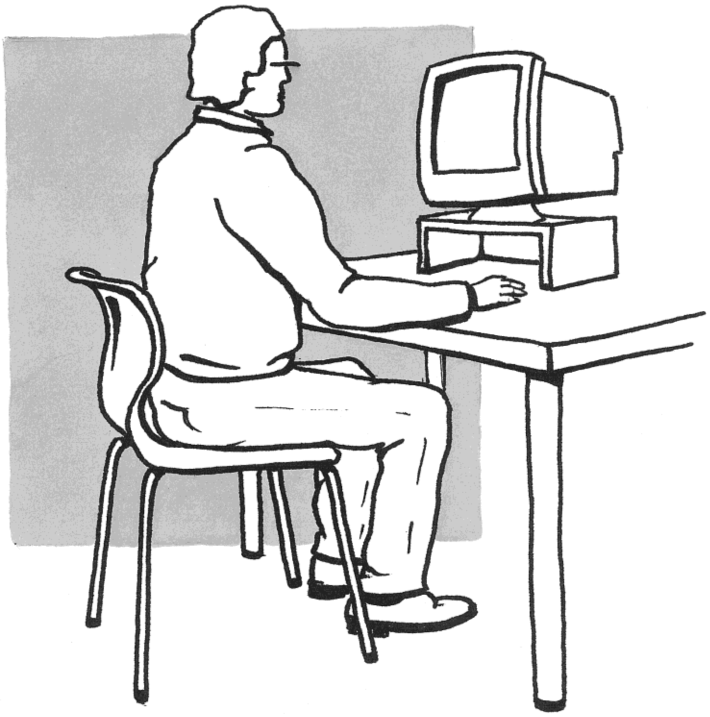

Figure 1-4: Correct upright, active posture with the screen at eyelevel and without use of the backrest.

that demands extra energy. And yet, this posture would seem momentarily to be perceived as comfortable, or, perhaps, people just do not know any other posture to adopt. Incidentally, with this posture the backrest is hardly used if at all.

Figure 1-5: A downwardly directed line of gaze results in a kyphosing posture.

The danger of 'computering' lies in the fact that one becomes so fascinated with what one is doing that the normal warning mechanism for physical strain is ignored and one eventually damages ones body by adopting postures that after long periods are highly taxing on the body.
This is another case where a further analysis of the phenomenon would be of interest: and especially the conclusions that could be drawn for future use.

Sitting behaviour, change of posture, is something that arises automatically. Partly this is caused by the line of gaze that is necessary for a certain activity, and partly by the body’s warning mechanisms that protect the body against overstraining. A change of posture means that the strain on the body is altered and that is apparently what it is all about. Sitting behaviour can, of course, be influenced consciously as well. Just realising what is going on when one is sitting can be enough to bring about healthy sitting behaviour.

1.2 Momentary comfort perception

One of the first tentative conclusions that can be drawn from the observations is that people are continually searching for a perception of comfort and that the duration influences that perception of comfort. Comfort can most easily be described as the absence of discomfort. One speaks of comfort when one does not experience any discomfort. Postures are adopted on the basis of momentary comfort perception: the perception on which the duration has not yet had any influence.

When one observes people sitting, it becomes clear that some factors that determine comfort are more important than others. One sees postures, and more especially details of postures, that could not possibly be comfortable. The hard edges of backrests digging into backs, buttocks that are nearly sliding off of seats, thighs numbed by the front edges of seats: it can all be seen and it does not only look very uncomfortable, it is very uncomfortable.
And yet these postures must initially be experienced as comfortable because they are often adopted. Frequently, in essence, these sorts of posture demand very little effort or energy to maintain.

It is remarkable, if one is watching out for it, how quickly people move from an upright, active posture to a posture that requires less energy as soon as the opportunity arises. As soon as a computer user stops to contemplate and no longer needs to use the mouse, then their buttocks slide to the front of their seat and their trunk reclines onto the backrest. Observe people during a meal and the same behaviour can be seen.

The conclusion may be drawn that low energy expenditure is a very important factor in the perception of comfort and apparently overrules certain forms of discomfort in the first instance. Some factors influencing the perception of comfort are apparently more dominant than others. In other words, there must be some sort of hierarchy in the factors that determine comfort.

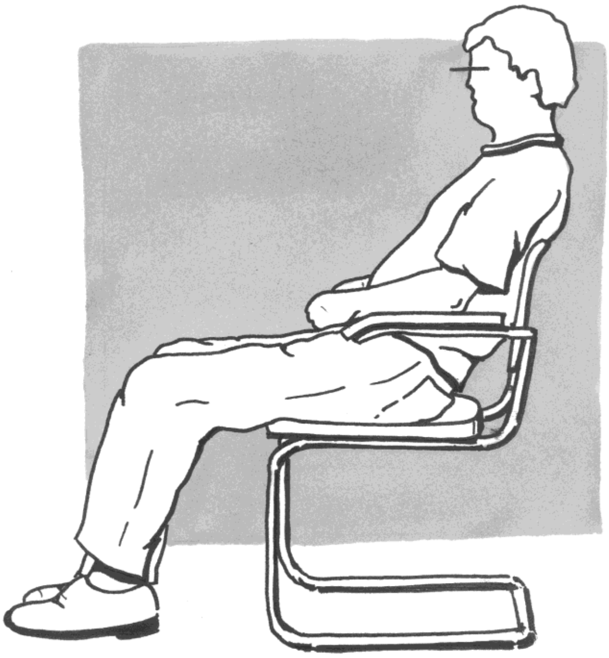

Figure 1-6: Hard edge of a backrest that is nevertheless used to find stability for the trunk by drooping down in the chair.

1.2.1 Stability of the trunk

If people no longer wish to exert themselves, they lie down. All parts of the body are then supported. No energy is needed to maintain this position: a requirement when one wishes to sleep. The body is in a *stable* position. If people are tired from standing, they sit down. If they are tired of sitting, they lie down. Sitting can be seen as an intermediate phase between standing up and lying down. It requires less energy than standing but more than for lying down.

In the descriptions of sitting behaviour it has become clear that within the possibilities for any chosen direction of gaze a person can choose between postures that require relatively more or relatively little energy. This has everything to do with *stability*.

A stable support for the trunk results in low muscle exertion, therefore it requires little energy and for that reason it is - unconsciously – given preference.
Sitting postures can therefore be assessed as to the extent to which and the manner in which they provide stability for the body. The body parts considered here are: the pelvis, trunk and head. Besides seating supports, arms and hands can also play a role in creating stability.
In figure 1-7 we see that the backrest is not being used and that the arms are leaning on the table. In this way the trunk is being kept in balance.

Figure 1-7: Stabilising the trunk by leaning on the table.

If the backrest of a chair is too upright and too high for the trunk to find stability when leaning against it, then the space above the armrest can offer a possibility for nevertheless creating stability for the trunk, as is demonstrated in figure 1-8.

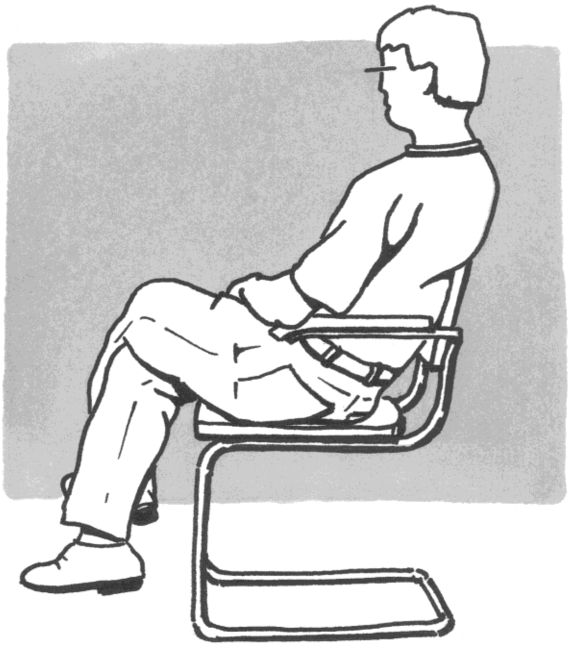

Figure 1-8: Askew in the chair so that the trunk can be reclined against and above the armrest to realise stability.

In a standing position, stability is also sought as soon as the opportunity arises. The scene in figure 1-9, leaning against a doorpost, must be a familiar one.

Figure 1-9: Leaning against a doorpost for a more relaxed, stable posture.

In the use of wheelchairs one sees a remarkable situation. People, who through physical limitations are forced to sit down all day long, using a wheelchair that is designed for them to sit in an upright, active posture all day, although, usually, they only have limited physical abilities to do this. We can then observe a situation such as in figure 1-10: stability for the trunk is sought by supporting the trunk from behind with an arm on the tubular sides of the backrest. Or, what can also often be seen: an elbow hooked behind one of the push handles in order to satisfy the need for stability.

The posture itself does not seem to offer any stability. This soon leads to a posture in which stability is found by arching the back and hanging in the ligaments of the spine. In this posture, the abdomen becomes greatly restricted and the back is – permanently – under a lot of strain. In this posture the head has to be lifted much higher to maintain a horizontal gaze.
Furthermore, having to sit upright and active in a wheelchair all day does not correspond with generally observable sitting behaviour which is always aiming for relaxation and therefore stability.

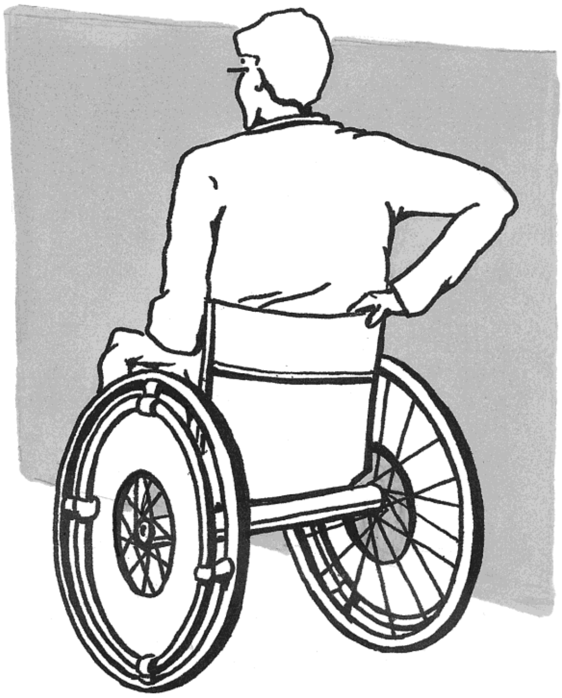

Figure 1-10: Stabilising the trunk with an arm round the tubular side of the backrest in a so-called active wheelchair.

1.2.2 Stability of the head

If, when observing sitting behaviour, one pays special attention to the head, one makes some surprising discoveries. The head is seen to be supported, very frequently and very subtly, as soon as an opportunity arises.
At the end of the day, when people are getting tired, a situation, as seen in figure 1-11, can often be observed. The head is resting in the palm of the hand. The head and the trunk are being supported in a stable position by the backrest and the arm. Clearly there is not much energy left to expend.

The muscles in the neck and shoulder no longer need to be activated and can relax.

Figure 1-11: Stability for the head through support from the arm.

A similar situation can be seen in front of a personal computer. The gaze is directed at the screen whilst the head is briefly being supported by holding the thumbs under the chin. A moment of relaxation: until the mouse or the keyboard are needed again. This is behaviour of which one is barely conscious but which demonstrates how energy and the perception of comfort are managed unconsciously and how important it is to – temporarily – relax the neck and shoulder muscles.

Figure 1-12: Stability for the head by supporting the chin.

Keeping the head in position costs energy and it has to be done all day long. Supporting the head brings a welcome change; it relaxes the neck and shoulder muscles and conserves energy. This is obviously experienced as comfortable. Judging by the frequency with which this phenomenon can be observed, it must be high in the hierarchy of momentary comfort perception.

1.3 Seats and cushions

Up till now, sitting behaviour has mainly been considered by looking at people and not by looking at the support afforded by furniture. One exception was made for car seats. There the conclusion was drawn that, for some reason, even for longer periods, the support apparently afforded comfort and the posture did not quickly lead to a feeling of discomfort.

There are many sorts of chairs and furniture available for sale. They are designed for a specific purpose and selected by customers for a specific use. Although it would seem obvious to assume that the functional purpose of a chair and the ultimate functional use correspond with each other, in practice that is often not the case. Many reasons could be the cause of this. Here it will suffice to ascertain that ‘mistakes’ can be made on both sides. The purpose of the chair can be badly implemented so that it is not optimally fitted for the envisaged use. The chair can also be selected on the wrong grounds: in other words, the planned usage of the customer does not correspond with the purpose of the seat.
Apart from functionality, furniture usually has another important aspect: people can distinguish themselves through their choice of furniture; they can stand out from the crowd and show that they belong to a particular social group. Design, image and social class are the keywords here. This applies to both companies and private individuals. Functionality need by no means be an obstacle for 'design' or 'image'. Good functionality should by definition be able to uphold a specific design. This book confines its analysis strictly to functionality.

Chairs usually afford a specific posture for a specific usage. A sitting posture is achieved through a certain configuration of the seat and back supports. The angle of the - burdened – supports in space determines the afforded sitting posture.
Up till now the observations of sitting behaviour have only been focussed on the influence of the posture on the momentary perception of comfort.
The perception of comfort is, of course, also influenced by the hardness or softness of the supports. It is interesting to see to which degree the purpose of a chair and the nature of the support, that is, the hardness or softness of the upholstery, is of influence on the possible perception of comfort.

There are a number of notable phenomena. Chairs that afford a relaxed posture and in which one is expected to converse or to watch television are usually provided with soft cushions. Sofas are often filled with loose, soft cushions. In advertisements for sofas one hardly ever sees people just sitting comfortably, but usually half lounging or lying, in a posture that looks comfortable but is often not really comfortable.

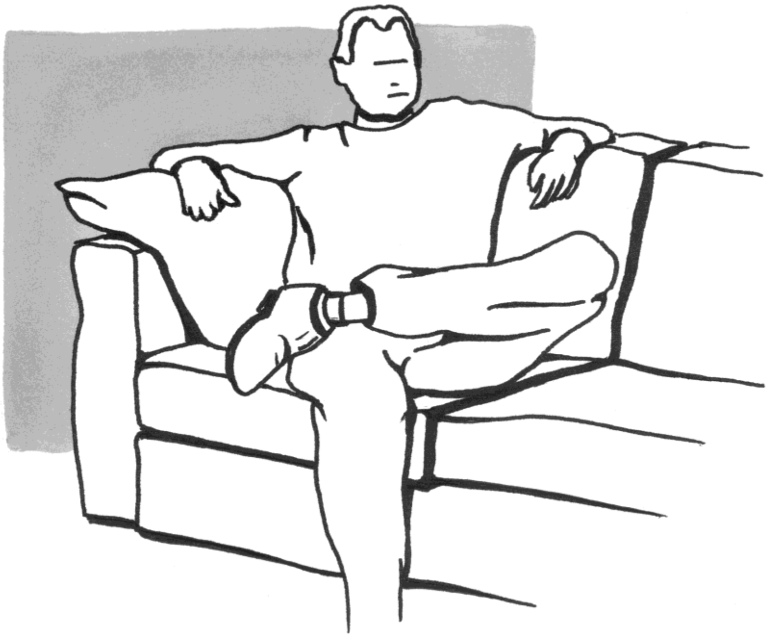

Figure 1-13: A characteristic sitting posture on a soft sofa with the arms over the backrest to create a comfortable stability, which cannot be achieved without the arms on the backrest.

So, there is something strange going on with sofas. You must be able to do, and may do anything with, in or on them, except sit properly. At least, that would seem to be the case. Softness is what is provided but often without an adequate posture that offers sensible stability. One has to resolve this for oneself with cushions or try to realise it with the aid of ones arms over the backrest. Result: restless sitting behaviour! Functionally, cushions can actually be seen as an admission of weakness in the design.

Armchairs seem to give more consideration to a comfortable sitting posture. The posture is based on conversation and watching television. The cushions are generally a little less soft than those in a sofa but here also one often finds loose, soft cushions with which one is supposed to make ones own posture more comfortable. The earlier comment applies here as well.

Dining room chairs usually afford an upright, active sitting posture with fairly hard support in the seat and backrest. One sees a multitude of models and materials. The seat can be woven rush, moulded plywood or it can be upholstered with a thin layer of foam covered with fabric.
Dining room chairs have a social function: they are for eating, conversing and listening in. These last two activities are best done in a relaxed stable sitting posture.
The trendy dining room chair from 2006 in figure 1-14 affords an active sitting posture. Due to the high backrest there are no other possibilities of finding stability and therefore relaxation. The result is that one seeks stability in a posture with an arched back and hanging in the ligaments of ones spine. The abdomen is restricted resulting, certainly after a copious meal, in an unpleasant sensation. At such a time one would, after all, prefer to have some 'room for digestion'.

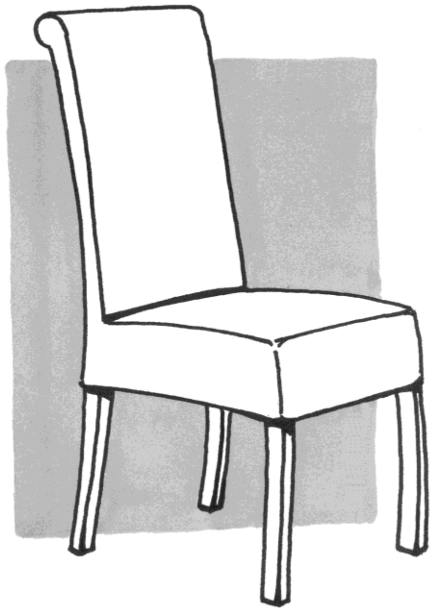

Figure 1-14: Dining room chair according to the trend in 2006 with an upright, active sitting posture.

Desk chairs that are used in meeting rooms and in halls where lectures and the like are held, usually afford an upright, active posture while the main activity pursued in the chairs is listening. People prefer to do that in a relaxed sitting posture on not too hard a seat cushion. The average stacking chair does not provide this. Often the seat is manufactured from plastic or moulded plywood. In the most favourable cases the seat is contoured to the form of the buttocks. Here, design would often seem to be more important than functionality.

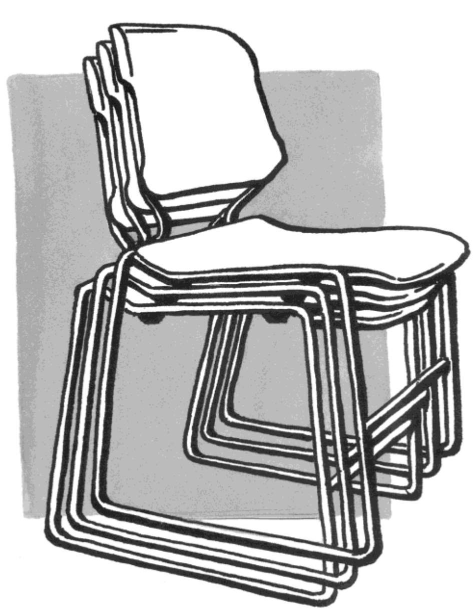

Figure 1-15: Easily stackable desk chairs with an active posture and hard support.

Office chairs fall under a special category. In most countries, office or desk chairs have to comply with safety and work standards. In the Netherlands this is the NEN 1812 standard. The chair must ride on five castors to ensure stability and the seat must be able to swivel on a central axis: this is a requirement dating from the time of the first IBM electric typewriter with a typeball. These machines were so high that a special *low-level* desktop was necessary for typists to use them properly. Usually these were placed at right angles to the main desktop and a swivelling desk chair seemed to be a handy solution. No consideration was given to the consequences for sitting behaviour. Natural sitting behaviour is almost impossible in this sort of chair. Each movement of the body results immediately in the seat turning. It is near impossible to push yourself up in the chair and adopt a different posture on the seat as one would normally do in a stable chair without castors. In fact – strangely enough – the chair offers too few possibilities for varied sitting behaviour, for a real change of support.
On studying the chairs on offer it is noticeable that the seats of desk chairs are usually more deeply upholstered than the seats of upholstered stacking chairs. It is also remarkable that the NEN 1812 standard mentions nothing about the qualities of the seat support.

It would seem that a chair in which one is supposed to sit actively usually has a hard seat and that as the less active and more relaxed the posture becomes the softer the seats are made.

1.4 Summary and conclusions

The most noticeable aspect of sitting behaviour is that people are continuously, and usually unconsciously, changing their posture. People seem hardly able to sit still. Nor do people want to expend much energy on sitting. As soon as they can, they change from an active posture to a more relaxed posture that calls for less energy. The keyword here is stability. The more stable the posture, the less energy necessary to maintain it. People are seen to be very creative in finding stable sitting postures on chairs that are not designed to afford them. Most desk chairs and dining room chairs presuppose an active use and an active posture. Yet, most of the time on these chairs is spent in conversation, listening or thinking. No problem. People still create the best possible stable, relaxed posture in spite of the chair by sitting askew in it so that they can move their trunk further back to find stability. With wheelchairs one can often observe that stability for the trunk is sought by hooking the elbows behind the push handles.
The time factor influences the perception of comfort. What, at first, is experienced as comfortable proves to be less than comfortable after a period of time. One changes ones posture - unconsciously – and chooses a new one that at that initial moment is experienced as comfortable. Careful observation of postures and methods of support shows that there must be a hierarchy in momentary comfort perception. The need to expend little energy would seem to be high in this hierarchy. We also place relaxation of the neck and shoulder muscles high on the hierarchy because people are frequently observed supporting their head with their hands, even if only briefly.

Driving a vehicle appears to be an exceptional activity in what is apparently an exceptional posture because people prove capable of maintaining the posture for long periods of time.
The general tendency of people towards postures with low demands on energy is not recognized in the so-called active wheelchair in which the user is expected to sit upright all day long in an active posture without stable support for their back. This quickly leads to a posture in which stability is found by arching the back and hanging in the ligaments of the spine.
Seat supports are usually fairly hard in active chairs and become softer as the presumed posture becomes more relaxed.

There must be reasons behind this observed sitting behaviour. Reasons that can explain it and that can guide the development of conscious sitting behaviour on well designed seats.

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2.0 Explanations for sitting behaviour

In chapter 1.0, observations were made on human sitting behaviour. Different sitting postures in diverse situations were discussed without a precise definition of sitting postures being given. To a significant extent, activities determine the postures that occur. To explain sitting behaviour, it is important to have a precise definition of a sitting posture to enable us to discover the secrets of that behaviour. This definition is related to the specific anatomical properties of the body and especially to the biomechanical consequences in a sitting posture. The sitting posture itself causes a play of forces that has an influence on the perception of comfort and for that reason must be further analysed.

Physiological and neurophysiological properties of the body determine the manner in which the loads on the body are dealt with and experienced internally and externally resulting in sitting behaviour as described in chapter 1.0. Insights into these properties are necessary to be able to explain that behaviour.

Before more attention is given to the (neuro)physiological properties of the body, the influences of the time factor will first be explained more fully.

After all of the relevant aspects for the explanation of the observed sitting behaviour have been discussed, the specific characteristics of *the individually preferred posture* and the phenomenon *stability* will be highlighted.

Finally, the manner in which cushions contribute to comfort will be discussed.

2.1 Comfort and time

A change of posture is the result of a continuing need for comfort. Comfort is a difficult concept. People feel comfortable when they do not feel anything in particular. Comfort cannot be specified precisely. One has a pleasant feeling all over the body. It is much easier to speak of comfort as the absence of discomfort. Discomfort is, after all, much easier to specify. One speaks of an ache in the back, pins and needles in the buttocks, legs that have gone to sleep, and so on and so on. Pain stimuli are transmitted to the central nervous system and, sometimes consciously but usually unconsciously, ‘measures’ are taken. The cause of the pain stimulus is removed: one adopts a different posture, one changes one’s position, the original body load situation is suspended and a new one is created that at that moment is experienced as comfortable. In the previous chapter this was called the *momentary comfort perception*. From the sitting behaviour of people it is clear that the time factor plays an important role in the perception of comfort. What was initially felt to be comfortable proves not to be at all comfortable a little later. The momentary comfort perception is to an important extent determined by the need for lack of any (noticeable) exertion and for stability. In the previous chapter this was one of the observations that led to the conclusion that there is some sort of hierarchy in the perception of comfort.

Localized heightened pressure on the body due to bad support is instinctively 'accepted' initially, but not for long. The movement of bodily fluids through vessels and tissue is essentially blocked and with it the supply of nutrition. That is all right for a short period, but not too long. The human body is, partly because of this, not suitable for *static* loading . It depends on movement, that is, on varying loading to be able to function properly, in both passive and active situations. Actively holding a clothes-peg open between the thumb and forefinger is something that can only be maintained for just over a minute. The flow of nutrients and waste products is blocked by the continuous muscle tension and triggers a change of situation: letting go of the clothes-peg. This allows the fluids to move again. A similar mechanism is at work during the external taxation of the posterior. The continual changing of posture is a natural result of this and as such it should be encouraged as much as possible, especially in situations where people may ignore or miss warning mechanisms due to intense concentration or through reduced ability such as during extended use of the computer or of a wheelchair.

2.2 The human body

Sitting postures are the result of the possibilities that the human body offers. The body can be seen as a chain of bodily segments that are connected to each other by means of joints. Muscles stretched over these joints can alter the position of these segments with regard to each other and can effectuate movement.

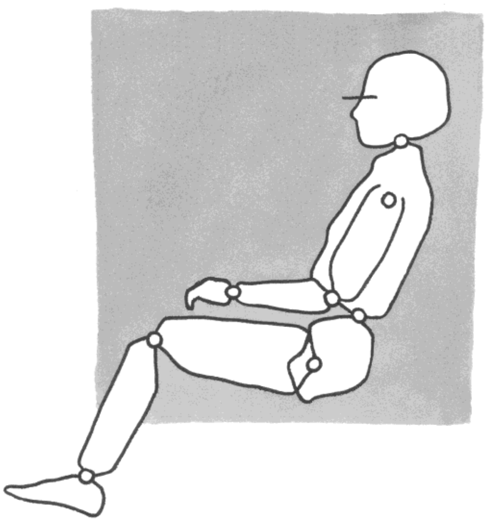


Figure 2-1: The body depicted as a chain of bodily segments.

For the sitting posture, the relative positions of the lower legs, the thighs, the pelvis, trunk and head are all important. The arms can play a role in the various postures either as an addition to or relief of bodily load. If they are not supported they are generally an additional loading, if they are supported they can add to the stability of the trunk and head.

The spinal column is an exceptional system of separate joints that work in conjunction with each other. The spinal column will be discussed in paragraph 2.2.2.

Posture and movement can only come about through signals from the brain: the control system. The explanation and understanding of comfort is only possible when the functioning of the control system has been explored in all its aspects.

2.2.1 Joints

Joints have a specific pattern of movement and range of motion that depend on the axes of movement and on the 'construction' of the joint. Ligaments, the bands of fibrous tissue around a joint, hold the joint together and help to determine the range of motion. Unless they are 'locked', as in the knee joints when standing, the most extreme joint positions are not usually perceived as comfortable. That is very easy to imagine when one realises that the muscles around a joint – in the most extreme positions of that joint – are either stretched to their maximum or actively flexed to a maximum. Each joint has its own so-called 'comfort zone', somewhere in the middle of its own range of motion. The position and scale of this zone is partly dependent on the position of the surrounding joints. Straightening one's knees whilst sitting upright is, for example, almost impossible without tilting one's pelvis backwards. This influences the comfort zones.
During sleep, when the body is in absolute rest, a person lying on their side will automatically adopt the most comfortable posture: the - comfort – hip angle is then approximately 135º just as is the angle at the knees: the angle between the lower leg and the thigh.
The momentary comfort perception of sprawling on the sofa, as is seen in figure 2-2, could quite possibly have this phenomenon as its origin – next to the requirement for stability – if it is temporarily placed high in the hierarchy of comfort perception. After all this posture has a great resemblance to the sleeping posture described above.

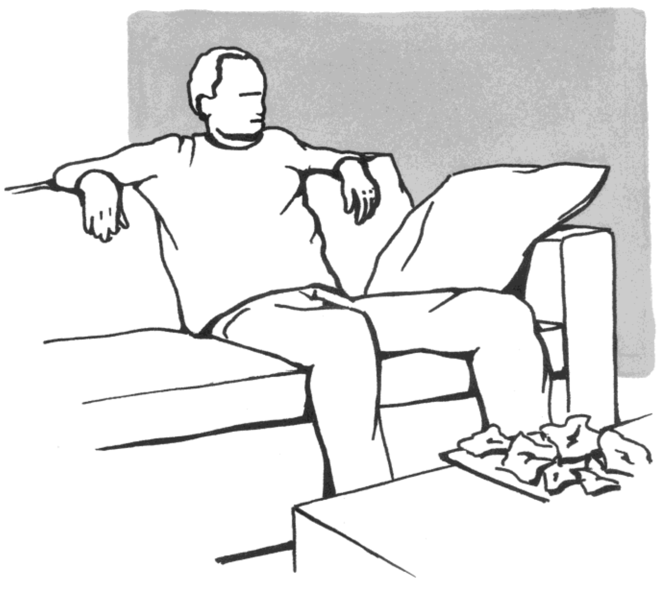


Figure 2-2: Sprawling on the sofa with two angles of approximately 135º and the arms over the backrest to give more space for the abdomen and stability for the trunk.

In the various different sitting postures that are observed there is repeatedly a parallel seen between the knee angle and the hip angle. In an active sitting posture we see 90º and 90º. If the hip angle increases then the knee angle also increases, indeed, the knee angle can only then comfortably increase because of the reduced tension on the hamstrings, the tendons in the muscles in the back of the thighs.

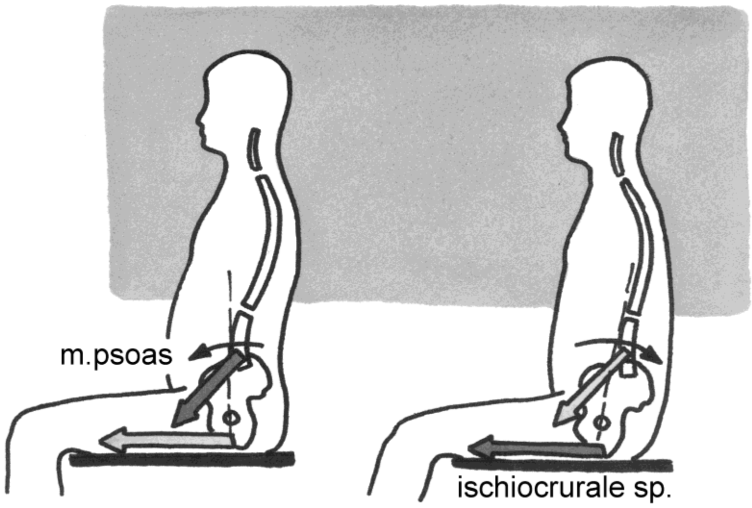
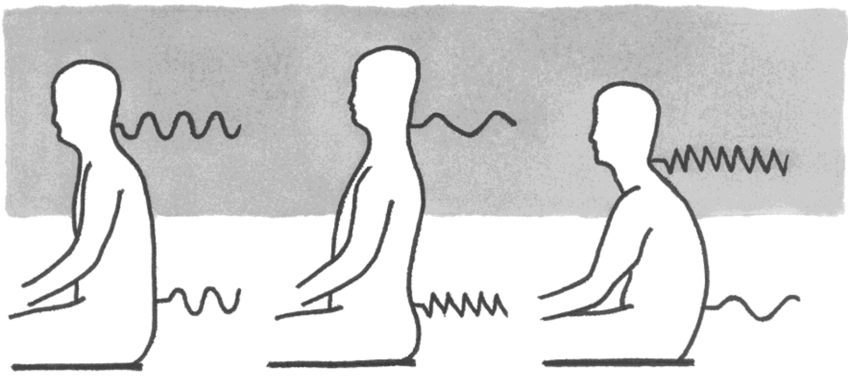


Figure 2-3: Muscles that influence the tilt of the pelvis.

The position of the pelvis plays a crucial role in the realisation of both an active and a – passive - supported sitting posture. Here, the position of the pelvis determines both the comfortable position of the legs and the position of the spinal column. The individual characteristics with respect to the shape and the segmental mobility functions of the spine in turn determine the positioning of the pelvis, in both standing and in sitting postures.
The muscle-joint mechanisms that play the most important roles here are:
• the m. iliopsoas: this has an indirect movement relation to both hip joints, resulting in a forward tilting of the pelvis,
• the polyarticular musculature of the ischiocrural group that, via an antagonistic function with respect to the m. psoas, is responsible for preventing the above-mentioned forward tilting and, during active straightening of the knees, even causes the pelvis to tilt backwards. All of this depends on the longitudinal tension of the ischiocrural group (hamstrings, triceps surae).
With increasing active flexion of the hip from a sitting position, the tension of the m.iliopsoas increases and the hamstrings should relax in order to allow movement in the hip joint. The knee extensors should now maintain constant tension or reduce tension, unless lifting of the thigh is initiated together with straightening of the knee. In both cases, the pelvis has a tendency to tilt over backwards onto the ischial tuberosities.

In an active sitting posture one can prevent tilting back of the pelvis by straining the m. psoas.

In the illustration in figure 2-4, the muscle activity is depicted as an electromyogram: a higher frequency indicates higher muscle activity.
In posture C one can see that tilting the pelvis back and arching the back demands little muscle activity but does result in extra activity in the neck to keep the head with the gaze directed at the horizon. Posture C is one that practically occurs on its own in a (wheel)chair with an upright, active posture when the person using it does not want to exert very much effort. Incidentally, posture C is highly taxing on the lumbar segment of the spine as will be shown later.



A: lumbar flat B: lumbar lordosis C: lumbar kyphosis

Figure 2-4: Muscle activity in various unsupported postures.

2.2.2 The spinal column

The spinal column is built up of motion elements (vertebrae, vertebral disks, ligaments, , neural, muscular and vascular structures) that by their specific shape with regard to each other all contribute in their own way to any posture and/or movement of the spine. The various segments of the spinal column normally each have a characteristic curvature:

- the seven cervical vertebrae form the cervical segment, which has a slight lordosis,
- the twelve thoracic vertebrae form the thoracic segment, with a kyphosis,
- the five lumbar vertebrae form the lumbar segment, with a lordosis,
- the five 'vertebrae' of the sacrum are fused into one and go on to the os coccygis (coccyx or tail bone) and together these form a kyphosis.

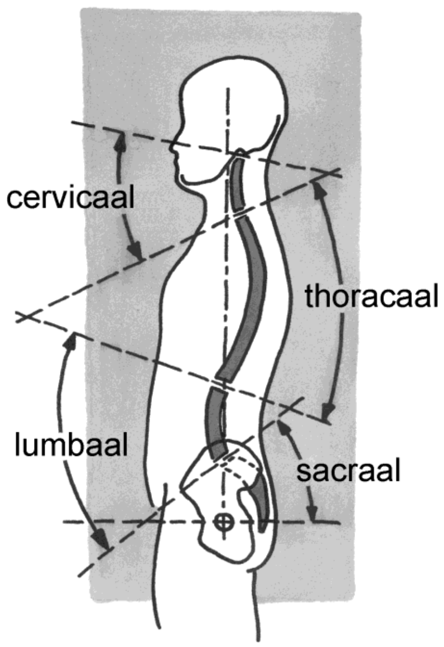


Figure 2-5: Shapes and names of the segments of the spinal column (sc)

The pelvis consists of a central rear part: the sacrum (S). The sacrum is joined left and right by a specific sort of joint (the sacroiliac joint - SIJ) to a hip bone (ilium) in which the hip joint can be found.
Both hip bones are joined at the front by the pubic symphysis.
These joint connections: SIJ and pubic symphysis are usually such stiff and resiliant connections that there is no possibility of any form of angular movement. Both when standing and when sitting, a lessening of the angle between the trunk and the legs – (passive) flexion of the hips - will primarily take place in the hip joints.

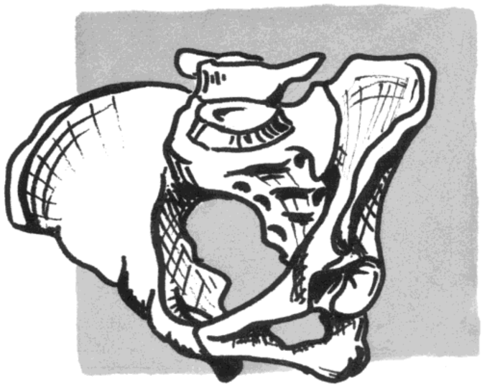


Figure 2-6: Pelvis made up of the sacrum and both hip bones.

The contribution to the mobility of the spinal column (sc) varies: the cervical and lumbar segments take care of most of the *forwards/backwards bending*, the thoracic segment does the *lateral bending*. The lateral bending is transformed into torsion about the vertical axis as a result of the restraining effect of the ribs in the chest (thorax). Pathologically, a permanent posture in which a person is bending laterally can lead to scoliosis, a more or less permanent curvature of the spinal column in the frontal plane. The lumbar vertebrae are joined to the sacrum and follow its movements. The position of the pelvis determines, to a significant extent, the shape of spinal column both during standing and sitting.

The spinal column takes a specific shape from the various segments that can be distinguished. These shapes influence each other.
The cervical segment of the spinal column can vary from hollow to arched, from lordosis to kyphosis.
The thoracic segment varies from less kyphotic to more kyphotic.
The lumbar segment varies from less lordotic to more lordotic.
The vertebrae are referenced by a letter and a number, for example, C7 is the seventh cervical vertebra from the top.

The curvatures of the spine contribute to determining the (physiological) mobility functions and are characteristic to an individual. In figure 2-7 shapes are shown that are considered to be normal and healthy.

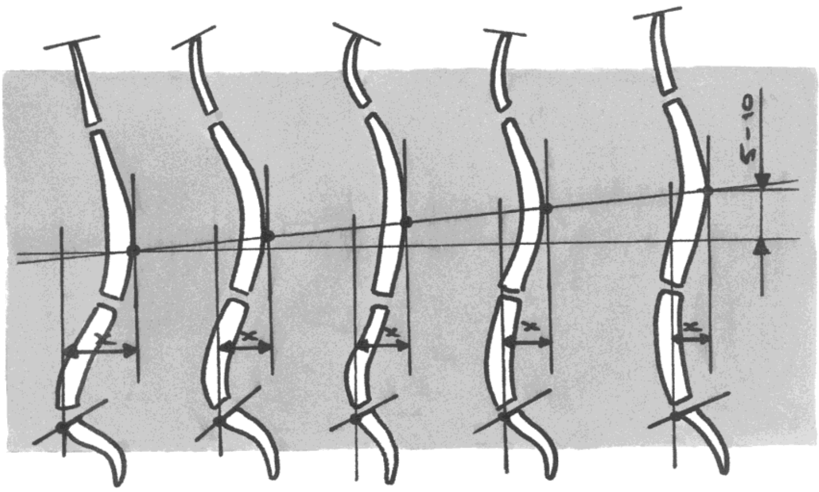


Figure 2-7: Healthy spinal column shapes.

The vertebrae are separated by intervertebral discs. These resilient elements between the vertebrae help to give the spinal column its flexibility and the capability to absorb shocks.
The vertebrae are connected to each other by a fibrous sheath, the ligaments. Because of this, the spinal column also has strength under traction.

The shape of the intervertebral discs varies according to their position in the spinal column: where this is most curved the intervertebral discs are more wedge-shaped and the lower on the spine the thicker the disc.
Where the intervertebral disc is thickest in relation to the height of the vertebrae, there the most flexibility can be found in the spinal column.

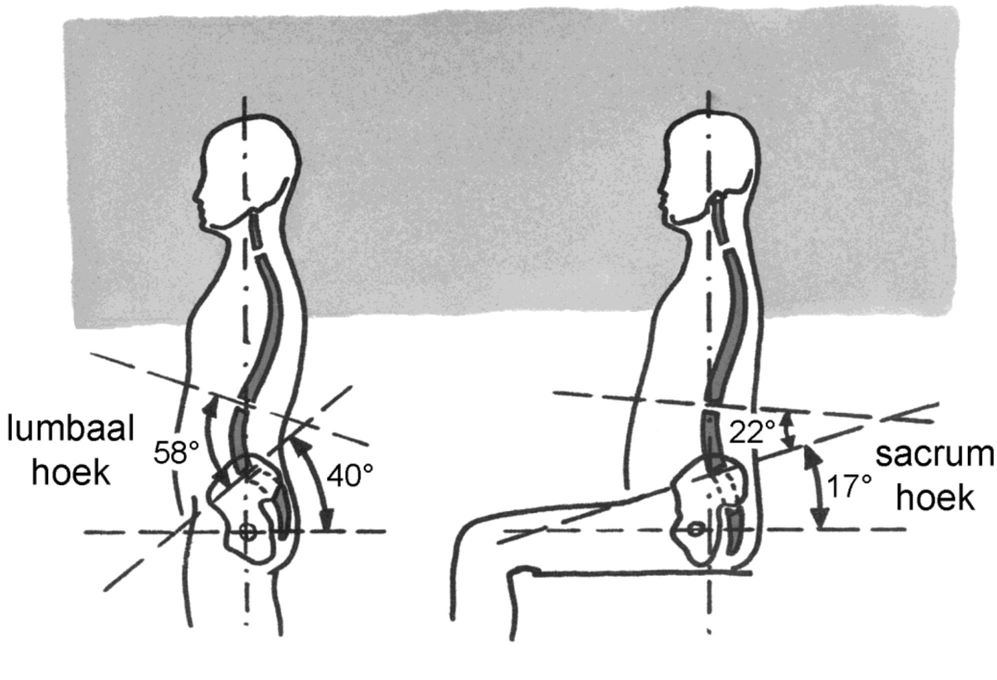


Figure 2-8: Flattening of the lumbar spinal column during sitting.

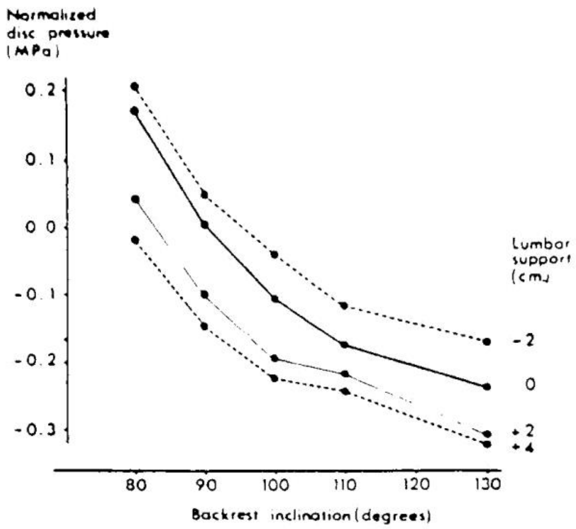
Between standing and sitting postures the back shows flattening in the lumbar segment, just above the pelvis.
The change in the position of the pelvis in relation to the trunk is the cause of this: tilting the pelvis backwards reduces both the sacral angle and the lumbar angle, from 40° to 17° and from 58° to 22° respectively.
Complete recovery of the standing lumbar angle is not possible because the muscles in the ischiocrural group will be stretched too far.

Maintaining the natural shape of the lumbar segment of the spinal column as closely as possible to its shape when standing, is a condition that must be met in order to achieve a comfortable sitting posture. In the standing posture the load on the intervertebral discs is, after all, evenly distributed and therefore the risk of overloading? is as low as possible

In an upright, active sitting posture, the pressure on the L3-L4 intervertebral disc is one and a half times the pressure when standing. If one tilts the pelvis completely backwards and passively hangs in one's back while sitting, as in situation C in figure 2-4, then this pressure can be as much as two and a half times as high. The result of frequent resort to this posture eventually leads to a maximum continual stretching of the ligaments along with turning off the proprioceptor/propriocepsis and interoceptor signals, signals that are sent from the muscles and joints to the control centre in the brain. See paragraph 2.2.3. This posture would seem to be relaxing for the muscles, but often it leads to a reactive hypertonia of the monosegmental innervated intervertebral musculature in the lumbar region, which can eventually result in a contracture of the joint. This posture is highly taxing for the ligaments and joint structures and is therefore undesirable for lengthy periods.   (tax: lay heavy burden on!!)

When the back is supported by a backrest, the pressure in an intervertebral disc depends on the position of the backrest in space (*backrest inclination*) and on the extent to which the back is individually supported *(lumbar support in cm)*. See figure 2-9. Plus 2 cm (+2) in the graph denotes that at the position of the small of the back a bulge of 2 cm thickness has been made in the backrest which slightly forces the back to take on its more natural lordotic shape. The definitions that are used in this figure, incidentally, deviate greatly from the definitions that are developed in paragraph 2.3.2 for defining a sitting posture.

The pressure at the reference point (0.0 on the vertical axis) is 0.51 MPa. That means that – 0.1 on the vertical scale represents a reduction in pressure of ca. 20%.
With an inclination of the (flat) backrest of 100º and a support in the small of the back of plus two centimetres thickness, there is a reduction of pressure of ca. 40% in comparison to a backrest inclination of 90º without any specific support in the small of the back. In view of human sitting behaviour where little consideration is given to how the small of the back is taxed, any extra taxation must be low in the hierarchy of *momentary* comfort perception.



The pressure at the point of reference is 0.51 MPa = 3834 mmHg.

Figure 2-9: Pressure in the intervertebral disc L3-L4 depends on the inclination of the backrest and the extent of individual back support (lumbar support) expressed in cm in relation to the flat backrest.

2.2.3 The control system in the brain

A human can be highly aware of their posture. With their eyes closed they know exactly where their feet are, what position their arms are in and which posture they have adopted.
Every sitting posture is, in a physiological sense, arrived at by control from the central nervous system, the CNS. A necessary condition for all actions and reactions in posture and motion is the unconscious detection of the position that the body or body part in relation to its surroundings.
Locomotory activity is therefore completely dependent on a properly functioning sensory perceptive ability.

The sensory perceptive ability is, along with the visual and the vestibular reactions from the semicircular canals in the inner ear, built up of:
- interoception, reception of stimuli from sensors within the internal organs;
- proprioception, reception of stimuli from the sensors in the muscle spindle, tendon sensors and joint sensors.
- exteroception, sensory stimuli from the skin, eyes and ears.

Stimuli from these various sensors are continually being fed through to the control system in the brain. This has the ability to make a person aware of their posture and their motion. It enables a person to determine which way is up, or down, left or right, and from which direction a sound is coming.
Just as visual stimuli are converted into a 'picture' in the brain, so are these stimuli converted into a realisation of posture and position in one's surroundings. One can 'picture' one's position, an ability which, incidentally, enables people who were born blind to develop locomotory skills.

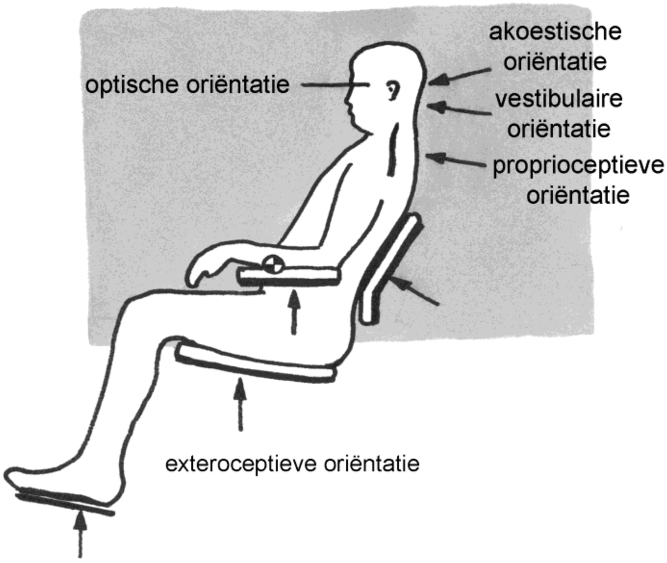


Figure 2-10: The sensory perceptive system.

Cognition, the realisation and knowledge of the way in which activities are carried out, proves to be a very important element in the learning of locomotory skills.

A person can consciously choose a certain posture. The muscles that are involved in the creation and maintenance of a chosen posture are, partly involuntarily and partly voluntarily, driven by signals from the control system. The control system 'knows' which posture is expected and starts running a programme to achieve it. Some muscles are flexed, others are relaxed, until the desired posture has been realised.
These muscle activities follow, to a great extent, a combination of automatic mobility patterns based on primitive posture reflexes, which are pre-programmed in the control system and are present from birth. In childhood one learns how these programmes work and through practice (by falling over and picking oneself up again) one makes new programmes for the most diverse, refined movements and postures.

The control system needs some reference to be able to do its work properly. Compare it with building a house where a spirit level is an essential instrument to be able to lay floors that are perfectly horizontal and build walls that are perfectly vertical. The human body also needs such an instrument to determine its position in space.

That instrument is formed by all of the sensors that perceive the balance of the head on the trunk and the programme in the brain that can interpret this information.
The head in balance on the trunk is a unique situation of unstable balance in which the least muscle activity is needed to keep the head in that position. This is directly registered and directly experienced.
Biomechanically and physiologically seen, this posture in which the head is in balance on the trunk is an extraordinary situation because the centre of gravity of the head with the gaze directed at the horizon lies ca. 20º in front of the atlas (the first cervical vertebra). In paragraph 2.4.1 this will be explained further.
The head in balance on the trunk with the gaze directed at the horizon can be considered the neurophysiological reference position. From this position the body can be most accurately directed to perform activities or manipulations, because the brain

has been trained in this way from a very early age, or to put it another way, has been programmed from this position.

The hard work of a child during its locomotory development provides a lot of information about how the human body adopts postures on reflex and how important the position of the head is in this.
A child that has at long last managed to pull itself up on the bars of a playpen and stands for the first time – albeit somewhat unsteadily – will maintain this posture until its gaze is inadvertently directed downwards. Then, suddenly, it will collapse like a jelly. The reference and with it the control of the posture reflexes has gone. The child will have to learn to orient itself to the horizon. Once it is able to do this it will learn to coordinate reflex activities in such a way that ever more accurate movements will be possible, which will gradually be more in tune with its own free will.
Strict orientation of the gaze to the horizon is, at a certain point, no longer really necessary. After a time the child will know with its eyes closed how it is standing and which movements it is carrying out. It will be able to touch the point of its nose blindfold. And if it does not succeed the first time, it will the second time. It will have learnt from the first go how it has to adjust its movement.

Although it would seem that the position of the head becomes increasingly less important for 'adult' functioning, this is not the case. The gaze directed at the horizon with the head in balance on the trunk continues to be the reference position for directing the posture and mobility apparatus. If - unconsciously – we fail to take this into account, the programming will go awry.

Motorcyclists know that when they are taking a corner they should not look at the road straight in front of the bike because then the risk of losing control over the bike and going off the road is far too great.

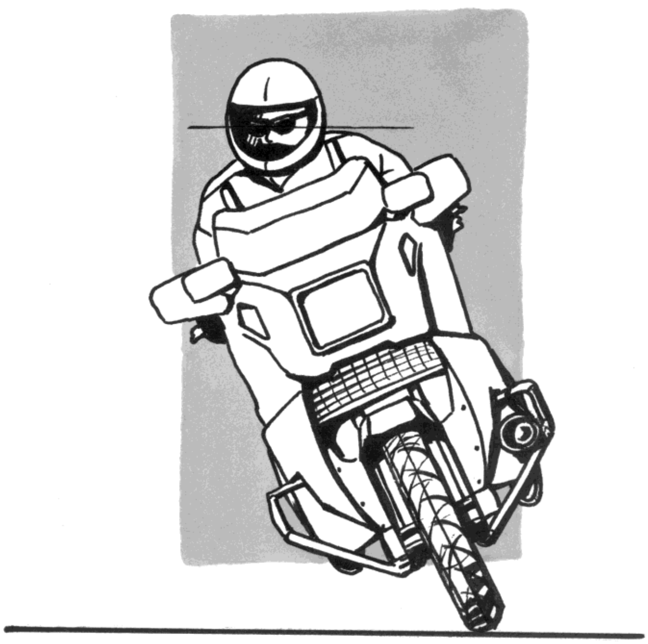


Figure 2-11: Motorcyclist taking a corner: eyes on the 'horizon' for precision control.

The control system is a self learning and self maintaining system. It must continually be fed with correct information, correct posture and movement patterns and with a continuous recalibration or confirmation of the reference.
The better the control, the better the movement and all the better the feedback.

Correct sitting behaviour leads to correct feedback and because of that to good fine-tuning of the control programme. Sitting in one posture for too long without reorientation, thus also without 'resetting', confuses the control system and therefore interferes with the control of posture and movement because there is no longer an unequivocal reference.
Furthermore, muscles that have been kept at a certain length for long periods have a tendency to consider this length to be normal. They give this state preference as being a newly experienced median position and send signals to that effect on to the control system.
This is also the case for joint structures.
These insights obviously carry great implications for people who through incapacity are forced to function while sitting in a wheelchair.

2.3 Biomechanics of sitting postures

It is possibly a strange idea that when one sits on a chair with a certain sitting weight, the seat of the chair reacts with an equal force on the buttocks. If the force were lower then one would drop through the chair. The reactive forces in the seat and backrest form a load on the body and are partly responsible for the development or absence of a perception of comfort.
Everyone can experience the fact that a recumbent posture is less taxing on the body than a sitting posture. To be able to understand comfort properly it is necessary to have a proper understanding of the influence of the various sitting postures on the external and internal loads on the body. But first, sitting posture has to be defined and preferably in such a way that this can be established both in the body itself and in the chair. Some abstraction of the human body is desirable here in order to reach proper insights.

2.3.1 Biomechanical model of the human body

The human body can be seen as a chain of bodily segments that are joined together by means of joints. Muscles on either side of these joints can influence the position of the segments with regard to each other and can initiate movement. In figure 2-12 these segments are derived in two steps.

The model consists of linked rigid body segments, each with its own dimensions and mass and its own centre of mass.
Especially noticeable in this model is the single pivot point in the small of the back. This pivot point represents the complex variety of possible movements of a number of lumbar vertebrae. This is a drastic simplification of reality which facilitates clear-cut biomechanical analyses.

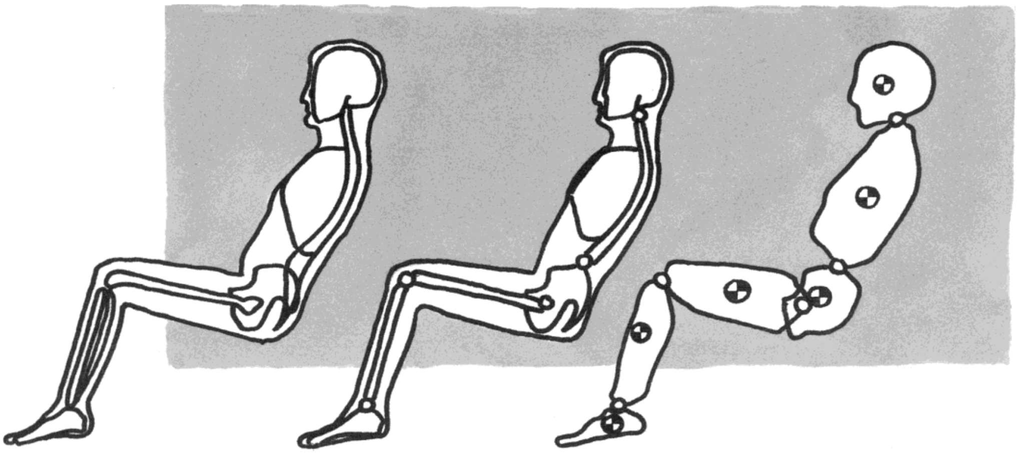


Figure 2-12: Deriving a biomechanical model of the human body.

The joints in the ankle, knee and hip have also been simplified to single hinges. The head is also linked to the cervical part of the spine by a single pivot point. In the model diagram the muscles around the joints have been omitted for clarity.

If dimensions and masses are given to the segments on the basis of anthropometric data then the result is a very satisfactory biomechanical model of the human body.

The mass of the bodily segments is deemed to be concentrated in the separate centres of mass.
With such a model, external and internal loads can be calculated.
The moments, which operate about the pivot points to achieve equilibrium, represent the loads acting on the muscles, tendons and ligaments around the joints. The reaction forces in the pivot points form the loads on joints.
If, in a certain sitting posture, equilibrium is achieved without the need for moments to operate on the pivot points, this means that, in theory, the posture can be maintained without any muscular exertion.

The model can simply be described as a collection of volumes, each with its own specific mass and centre of mass, joined together by pivot points.

The purpose of the developed model is to enable an analysis of the principles of the biomechanical aspects of sitting postures. Seen in this light, an exact determination of the location of the centre of mass of a given segment is less significant than the notion that there is a centre of mass and that, according to the model, the acceleration of the gravity (gravitational forces) begins to take effect at that point. This is also true for the schematically represented positions of the various pivot points.

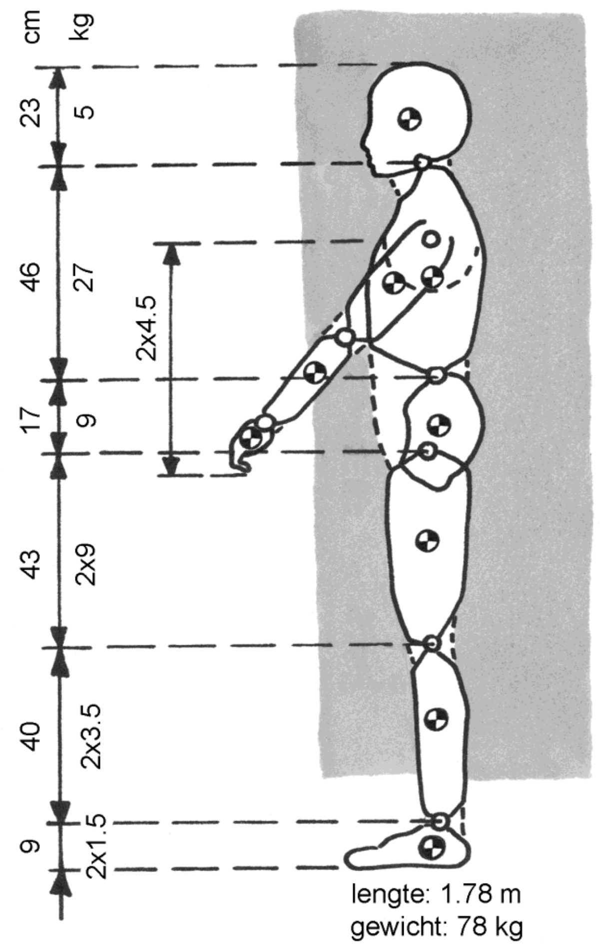


Figure 2-13: Biomechanical model of the human body.

The model can be used to adequately define a sitting posture, to gain insight into the size and direction of the internal and external loads, to optimise sitting postures and to research the influence of the reduction or loss of muscle function on the ability to maintain a posture.

In the model we can, for example, see that the pelvis, upper trunk, head and arms have a total weight of 51 kg. Together the arms weigh 9 kg. That is 18% of the total weight of the upper body. Supporting both arms in a sitting posture can, therefore, effect a reduction of 18% of the load on the sitting surface of the buttocks! This is not a trivial matter for wheelchair users in view of the need to prevent pressure sores).

From the model, a 3D test dummy (figure 2-14) on a scale of 1 to 2 can be made to demonstrate certain phenomena such as stability and frictionless sitting. Wheels can be added to the thighs and back so that the test dummy can only sit in a posture without friction between the seat of the chair and the thighs of the dummy.

Figure 2-14: 3D loose-jointed test dummy with tiny wheels in thighs and back to enable demonstration of stability and frictionless sitting.

2.3.2 Definition of sitting posture

A sitting posture is arrived at with the aid of the ‘supporting components’ of a chair, which, collectively, ‘afford’ a specific sitting posture. The positions of the supporting planes in space are often specified to give the sitting posture afforded by a chair. In chapter 1.0 detailed descriptions were given of the great number of sitting postures that can be adopted in any given chair. It is important to come to proper agreements on how to define a sitting posture.

Sitting posture can best be defined from biomechanical and physiological perspectives, because from there explanations can be found for the adoption of certain postures in relation to activities and for the analysis of preferred postures or disorders related to posture.

A sitting posture is defined by the mutual position of the body parts that are biomechanically and physiologically relevant, in relation to each other and their collective position in space.

In order to relate this to the 'afforded sitting postures' of chairs, the planes of contact along the bodily segments are taken as reference planes and the angles of the various segments in relation to each other are defined using these. The position of the thighs is defined in relation to the horizontal. From this point, the position of the various body parts in space can also be calculated. This approach is not only biomechanically relevant but also practical.

The consequence of this approach is that the posture that a chair (or other piece of furniture) affords has to be measured under load. That is no more than logical because this is, after all, all about the functional result.

The basic sitting posture is thus defined by the angles φ, α, ß, γ and λ.
In figure 2-15, the defined angles are illustrated.

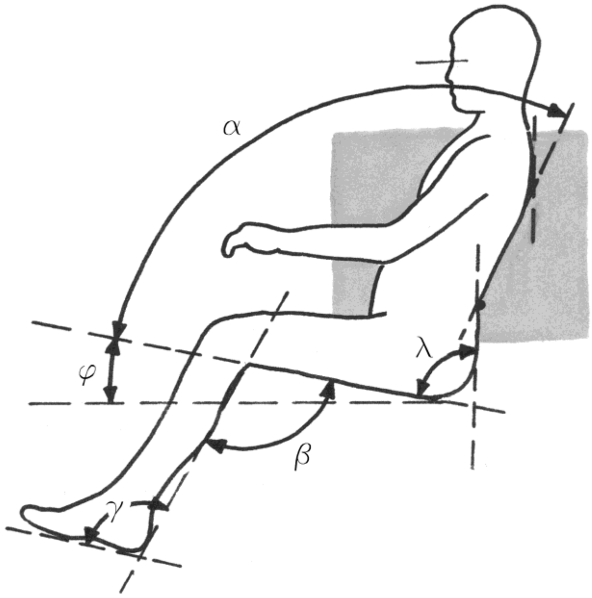


Figure 2-15: Classification of the angles that determine the sitting posture in the sagittal plane.

• Angle φ , the seat angle, gives the position of the contact plane on the underside of the thighs in relation to the horizontal. Angles above the horizontal are taken as being positive. As all other angles are defined in relation to each other, angle φ actually represents the position of the body in space.

• Angle α , the sitting angle or hip angle, gives the position of the contact plane on the back of the upper trunk segment *above the small of the back* in relation to the contact plane on the underside of the thighs. From this definition it follows that the position of the trunk in space is determined by the angle(φ+α). Angle(φ+α) is called the functional backrest angle.

This definition of the position of the trunk is essential for an understanding of stability. This definition stands *irrespective* of the individual variations that can be observed in the curvature of the small of the back in humans.

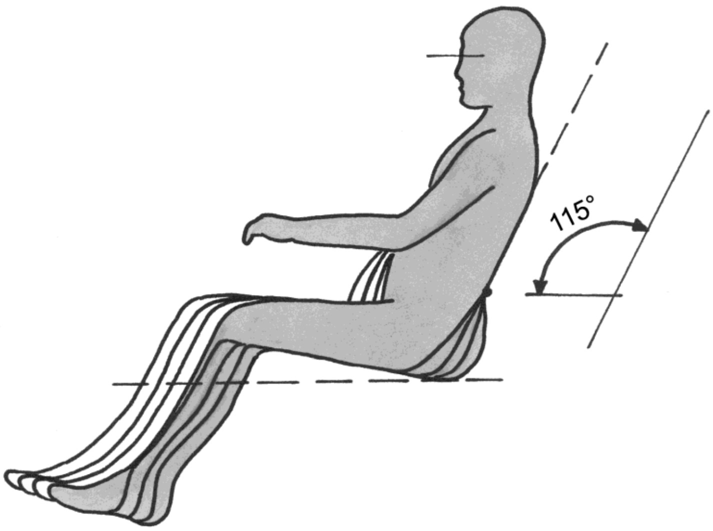


Figure 2-16: The definition of angle α applies irrespective of the shape of the back.

In a lot of the literature, the backrest angle α is defined using the line of contact along the back and the sacrum. The shape of the lumbar segment of the back is then defined as an individual characteristic of a person and as being the greatest depth that can be measured from the contact line along the thoracic and sacral regions of the back in the direction of the lumbar segment of the spine. This is what has been done in figure 2-9 where the depth of the small of the back is indicated in centimetres in relation to a flat backrest.
This definition is biomechanically incorrect because the position of the trunk in space does not depend on the depth of the small of the back. This definition is extremely confusing and not at all relevant. Furthermore, it is unpractical as a backrest inclination defined in this way cannot be measured in the case of a backrest with a clearly pronounced support for the small of the back.

This will be covered in detail in the discussion on the phenomenon stability.

• Angle λ gives the position of the pelvis in relation to the thigh. Angle λ is defined by the angle between the plane of contact on the back of the pelvis and the plane of contact on the underside of the thighs. To put it another way, angle λ indicates how much room there is for the buttocks in the chair.

• Angle(α - λ) describes the shape that the lumbar segment of the back takes on in the sitting posture. If this angle is positive, then the spine displays a lordosis and the size of the angle indicates the degree of the lumbar lordosis.

• Angle ß describes the angle between the line running from the back of the knee to the back of the heel, and the line of contact on the underside of the thighs.

• Angle γ describes the position of the ankle joint as being the angle between the underside of the foot and the line running from the back of the knee to the back of the heel.

With these definitions of the angles in the sagittal plane, (sitting) postures can be described with sufficient precision and recorded in figures. Asymmetric sitting in relation to the sagittal plane, for example when one leans sideways, requires a separate definition.

The 'sitting posture' afforded by a chair can, in principle, be described and recorded using the angles φ , α and λ. The chair should be measured under load. In the case of a wheelchair, the angles ß and γ can also be given.
If the body is capable or can be rendered capable of following these 'angles' closely, then the body will indeed adopt this position. If this is not possible or if this does not happen, then, in theory, a different sitting posture will result than the one afforded by the chair.

2.3.3 Sitting posture as source of external load

The seat and backrest of a chair support the body in a sitting posture. The floor or footrests take the weight of the feet and lower legs. The distribution of the load over the body depends on the sitting posture and on the presence or absence of back and arm rests. When sitting on a stool, the sitting weight will be ca. 80% of the total body weight.
If the back is supported, the backrest will take up more of the load as the backrest inclination angle($\varphi+\alpha$) increases and the seat will receive less load. The use of armrests reduces the load on the supporting surface of the buttocks considerably, as indicated in figure 2-17.

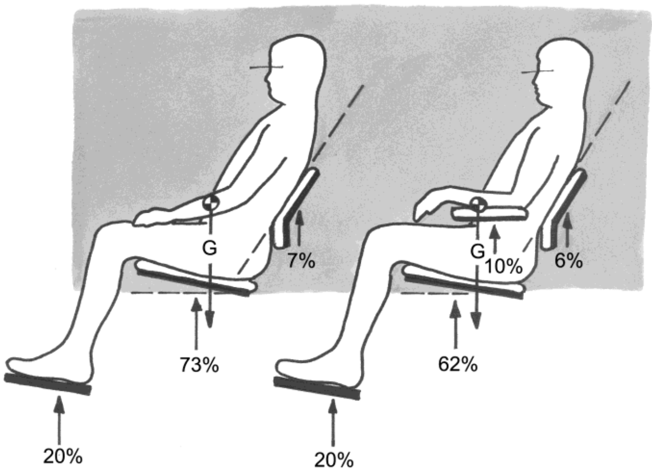


Figure 2-17: Distribution of weight in a relaxed posture without and with armrests.

The influence of sitting posture on bodily loads is evident and can be experienced by anybody. The extent of the load on the supporting surface of the buttocks is directly related to the internal load on the back.

In a sitting posture there is always an equilibrium of forces, otherwise one would drop through the chair or simply slide out of it. The fact that one does not slide out of the chair often means, in practice, that there is friction between the seat of the chair and the thighs that prevents this. This friction pulls, as it were, on the skin of the thighs and after a time this is perceived as uncomfortable. The flow of blood is hampered. Result: there is no longer any momentary perception of comfort and one changes one's position.

A *good sitting posture* could therefore, in view of this, also be defined as a posture in which no friction is necessary to maintain an equilibrium of forces. The question is then, whether such postures exist. The answer is: yes. For every backrest inclination there is, in theory, a seat inclination to be found that ensures that no frictional force is needed to balance the forces. Seats in which one is expected to sit for long periods of time, such as seats in airplanes, armchairs and wheelchairs should afford this sort of sitting posture. One practical problem here is that the greater the seat inclination – under load - becomes – and this becomes greater as the angle(φ+α) increases - , the more difficult it becomes for one to get out of the seat. This can be a problem for the elderly and for wheelchair users, especially.

Figure 2-18: Loose-jointed test dummy in stable sitting posture without friction on the seat or backrest.

The phenomenon of frictional forces, of the momentary perception of comfort, of the definition of sitting posture and the relation between sitting posture and activity became apparent in a surprising and clear manner after the analysis of the results of an experiment during a course.
The students were asked to: find a posture in an adjustable (wheel)chair in which you would be able to watch television for long periods.

The average result was as follows:

angle $\varphi = 12^o$ angle $\alpha = 107^o$ therefore angle$(\varphi+\alpha) = 119^o$

Next the experiment was repeated with a double layer of thin, slippery fabric (spinnaker cloth) on the seat. This 'construction' can barely absorb friction forces.
The average result was then as follows:

angle $\varphi = 15^o$ angle $\alpha = 103^o$ therefore angle$(\varphi+\alpha) = 118^o$

NB: No significance can be attached to the absolute values because the measurements were taken on the frame of the chair. Nevertheless, these values are not unrealistic.

What is remarkable about this result?

In the first place, the final result of both experiments gives the position of the upper trunk in space, angle$(\varphi+\alpha)$, to be the same within 1^o: apparently the criterion for judging the comfort of the posture is to be found here. As the gaze is directed at the horizon (the television), the head is in the same position on the trunk in this posture. Only the distribution of degrees over the angles φ and α is different. The double layer of slippery material makes it necessary to increase angle φ in order to prevent the feeling of sliding out of the chair. Subsequently the angle α is decreased, apparently due to the urge to have the trunk in the same position in space.
In the first task the perception of friction on the thighs was clearly not decisive in the short moment taken to judge the comfort of the posture. This confirms the hierarchy of perception of comfort and the influence of time that was arrived at earlier.
This observation will be discussed further in the section on the individually preferred relaxed posture.
This same experiment was repeated in the search for a comfortable work posture. The results showed a similar trend.

2.4 The individually preferred sitting posture

If people are asked to carry out a particular task, to write a letter or to watch television, then they adopt a posture that fits with the direction of gaze necessary for carry out the task. Driving a vehicle is, from an abstract point of view, the same as watching television, if we consider a television as being placed at eye level. A car seat is usually adjustable, most armchairs and sofas are not. Driving a vehicle is something that people can do for long periods at a stretch. On a sofa or in an armchair, people change their posture very quickly in spite of the presence of a lot of soft cushions. What is the secret behind this phenomenon? What is going well, what is going wrong? If this can be understood, then it should be possible to design perfect seats where these are needed for long periods of sitting such as airplane seats and wheelchairs. Maybe with this knowledge even the car seat could be further perfected.

In 1997 the author started his own research on quantifiable criteria for good sitting postures.
This research was not carried out for the sake of research but was necessary for industrial product development. The aim was to develop a wheelchair with individual seating support. The questions formulated were: what shows you that someone is sitting properly, what influences this situation and how many ‘good’ sitting postures are there in fact and how individual are they?
For the purpose of this research, a fitting chair was developed in which many variables and posture angles can be adjusted. See figure 2-19.

Figure 2-19: The developed fitting chair with central support of the spinal column by means of rectangular elements. Notice how the curvature of the spinal column can be seen at the back of the chair.

The back support consists of a system of similar flat rectangular elements of 30 mm thickness that can be adjusted in the sagittal plane completely independently of each other. At the back of the fitting chair one can see exactly what the spinal column is doing in the contact plane and what sort of individual curvature there is. The backrest inclination that was defined earlier, angle($\varphi+\alpha$) can be precisely measured at the back of the chair.
In the fitting chair, the position of the seat in relation to the horizontal can be adjusted by means of a spindle. The position of the backrest in relation to the seat (angle α) can be adjusted by an electric motor. The combined seat and backrest can be tilted by electric motor. This eventually gives the position of the trunk in space: angle($\varphi+\alpha$).

With all of these possibilities the key question is: how can a process for optimisation be started without the process itself getting in the way of individual optimisation? In other words: what must be done first and what last?

The body of a test subject can be easily manipulated if it is offered a stable posture in which it can relax. A stable posture proved to be achievable using a surface of only 150 mm high and 120 mm wide positioned from Th 9 to L 2/3, that is, a support *above* the lowest point of the small of the back, when angle($\varphi+\alpha$) is ca. 117° and angle φ is ca. 13°.

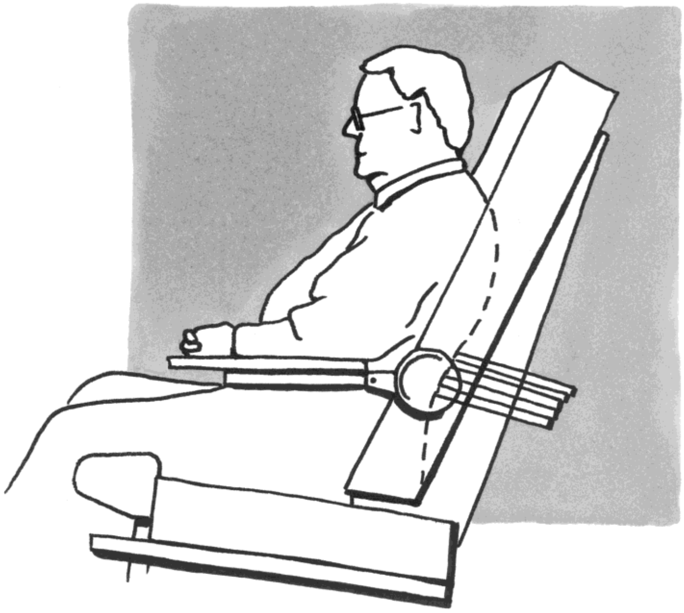


Figure 2-20: Support of the lumbar-thoracic transition area in a stable sitting posture as starting point for the optimisation of an individual back support.

With this initial posture, the position of the trunk in space, angle($\varphi+\alpha$) is defined.
In this initial posture with this minimal support for the upper trunk, we then find/search for the correct position of the backrest in relation to the seat to enable us to follow or to influence the individual curvature of the spinal column. In figure 2-21 we can clearly see the effect that the positioning of the backrest in relation to the seat has on the individual curvature of the spinal column.

Figure 2-21: Influence of placing the backrest in relation to the seat on the curvature of the spinal column.

In the next step, the lumbar, sacral and the higher thoracic segments of the spinal column are supported by placing all of the other elements of the back support against the body with the lightest possible pressure so that no correction takes place and then fixing the elements in place. By this action the pelvis angle, angle λ is also realised. A silicon bag full of granules is then used to fill the spaces next to the central part of the fitting chair and the air is removed from the bag by vacuum. Now the total individual back support has been realised. During this research the results of this approach proved to be readily reproducible.

This procedure for realising an individual support for the spinal column has continued to be the start of the author's own research into sitting. The size of the seating angle, angle α is kept more or less constant at 103°- 105º, a value that can be found again and again in the literature on similar research.

The first research was concerned with finding a posture in which one could watch television comfortably. The test subjects were asked to find themselves a comfortable posture – 'their individually preferred posture' – by adjusting angle φ and thereby also angle(φ+α). Surprisingly, this posture proved to have an functional backrest angle: angle(φ+α) of 123° plus or minus 2° for all 9 test subjects (young, old, with a mobile or an immobile lumbar spinal column) The variance between these very different individuals proved to be extremely small.
It appears that people experience a comfortable sitting posture when their head is '*in balance on their trunk*' and their gaze is directed at the horizon. People seek out this posture intuitively and experience it instantly. This can be explained neurofysiologically by way of the posture regulation from the vestibular and optical information and the primitive reflex activities, as described earlier. The moment at which the head is in balance on the trunk can be detected with a little bit of practice. Conversely, it was possible to put the test subjects into the same postures that they had previously chosen as comfortable.
When the head is in balance on the trunk, only minimal muscle effort is needed to keep the head in that position. Neck and shoulder muscles can therefore relax to a maximum and that gives the perception of comfort!

During the research into sitting using the fitting chair, photos were taken of the various postures. With the aid of the visible shape of the back support at the back of the chair, drawings were extrapolated from these for analysis (figure 2-22).

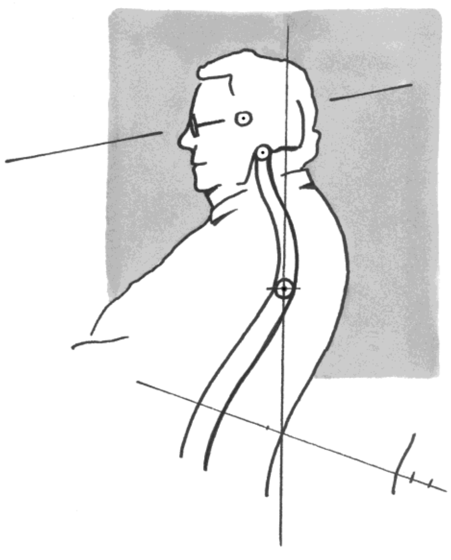


Figure 2-22: Graphic interpretation of a fitting result.

In figure 2-23, the individually preferred postures are recorded for two people with a clearly differing shape of the thoracic spinal column. Note that the individually preferred posture for both test subjects gives the same angle(φ+α), an angle of 122°. Nearly the same value was found for other test subjects, as described earlier. The question now arises: are these results due to coincidence or can we detect a line here?

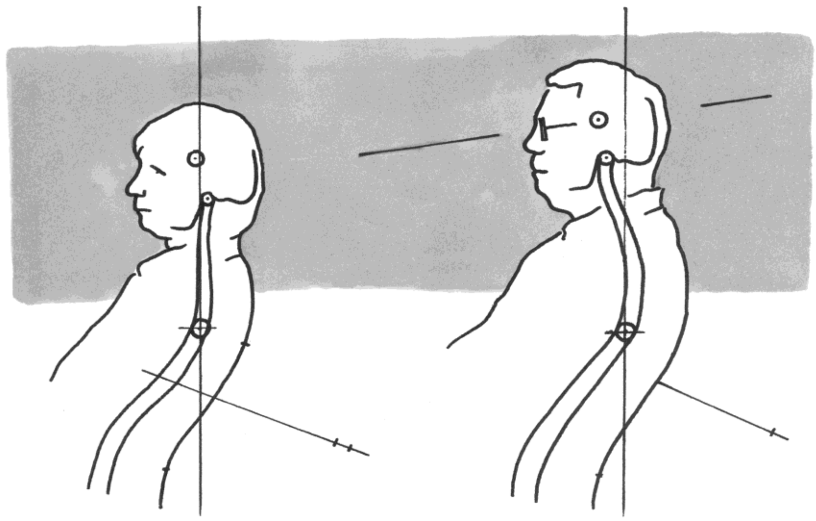


Figure 2-23: A clearly differing thoracic kyphosis but nevertheless the same individually preferred posture. Angle(φ+α) is 122° in both cases.

In *The Development of a Rest Chair Profile for Healthy and Notalgic People*, Grandjean (1969) describes research into the preferences for sitting postures of 68 test subjects using 5 different back support profiles. In figure 2-24, the final result of this research is shown with, *according to the author*, a backrest angle of 106º to 107° and a seat inclination of 19º to 21º. It is not clear how these angles are defined.
If, however, we apply the definitions for sitting posture described here, then this chair proves to have a functional backrest angle: angle(φ+α) of 123° and an angle φ of 18°.

These results reached by Grandjean cannot be based on any other perception of comfort than the results reached using the fitting chair, namely, relaxation of the neck and shoulder muscles due to the head being in balance on the trunk with more or less individual support of the back. Here confirmation of the results of this author's own research is found and at the same time the results of Grandjean's research are understood.

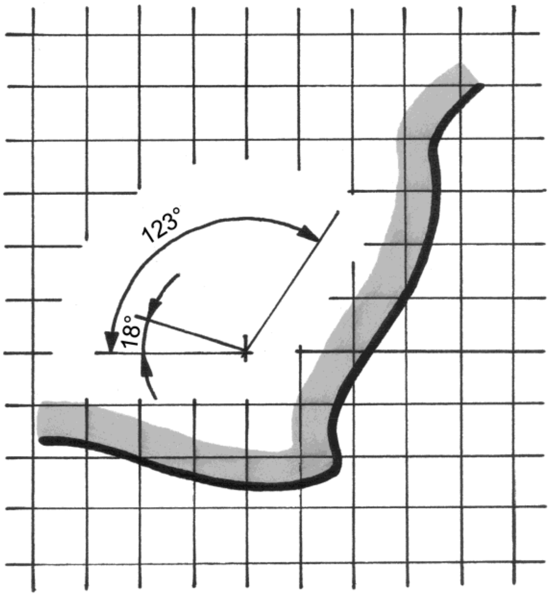


Figure 2-24: The seating profile developed by Grandjean for people with back complaints. Superimposed onto the figure are the angles according to the definitions in this book.

These results reached by Grandjean cannot be based on any other perception of comfort than the results reached using the fitting chair, namely, relaxation of the neck and shoulder muscles due to the head being in balance on the trunk with more or less individual support of the back. Here confirmation of the results of this author's own research is found and at the same time the results of Grandjean's research are understood.

If the above measurements (fittings) are carried out again using a flat backrest whereby the back has no individual support, then the individually preferred postures deviate clearly from the results found earlier. Sometimes angle($\varphi+\alpha$) becomes greater and sometimes decidedly smaller. The shape of the back proves to influence the balancing position of the head on the trunk.

If all of the measurements are taken again after one month, then the results using individual back support barely differ from the earlier results: the results of measurements taken without individual back support show surprisingly large deviations. The explanation for this is that a back that has no individual support displays a reactive muscle hypertonia that makes it very difficult for the test subject to perceive accurately how their head is balancing on their trunk. If these tensions are not present, as with individual back support, then, time and again, the balance position of the head proves to occur in one and the same posture. This is a notable achievement for the human body and, in particular, for the refined sensory perceptive abilities of the control system in the brain.
Again this leads to the conclusion that the procedure followed to give the back individual support is easily reproducible.

Individual support for the back is a precondition for a *proper* perception of comfort in the realisation of the individually preferred posture. An individual support is achieved –

simply defined - when - to start with - the trunk is supported *above* the small of the back in a stable posture and, below that, enough space is created for the buttocks. Demonstration experiments with the Red & Blue Rietveld chair clearly show the effect of individual support of the back.

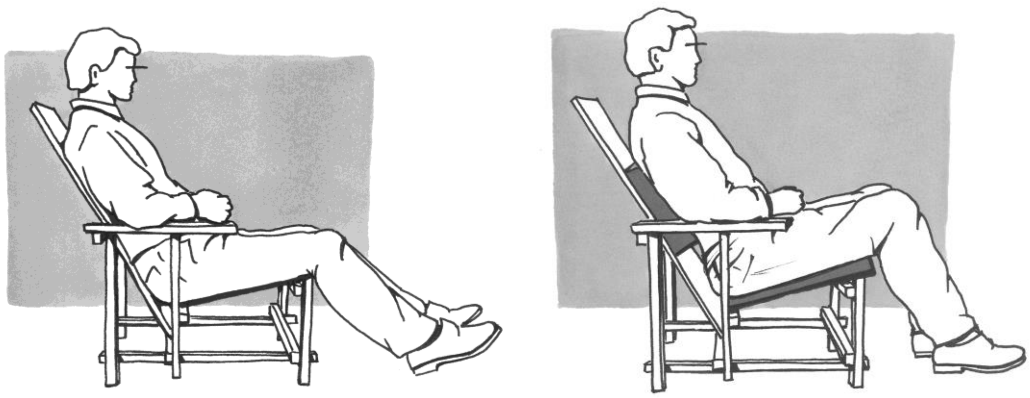


Figure 2-25: Red & Blue Rietveld chair: left in the original form: angle(φ+α) is 118º, *right with individual support above the small of the back: angle(*φ+α) is 123º *and with a greater seating angle.*

In figure 2-25, the left-hand drawing shows the original Red & Blue Rietveld chair with an angle(φ+α) of 118º. In the right-hand drawing a support surface has been added to the backrest above the small of the back which makes angle(φ+α) 123º. The seating angle, angle φ has been increased to 16º by means of a wedge. This support surface provides
space for the buttocks and for the individual curvature of the spine. Although the backrest inclination is 5º greater, the right-hand posture does not only look much more active than the left-hand one, it is also more active.

From the experiments with the fitting chair and Grandjean's results, the conclusion may be drawn that a relaxed individually preferred posture with the head in balance on the trunk, expressed as the defined functional backrest angle: angle(φ+α), is less individual than one would at first imagine. This preferred posture has an average backrest inclination, angle(φ+α) of roughly 123° as long as the back is given individual support in the manner described above.

This result obviously has implications for the way in which one watches television, drives a vehicle, sits in an airplane seat or wheelchair, or for the way one should sit if one wishes to do so comfortably and for long periods.

2.4.1 The head in balance on the trunk

The head in balance on the trunk is an exceptional situation that needs further explanation.

If the 'head is in balance on the trunk' when a person falls asleep in a chair, then the head should fall backwards in 50% of all cases and forwards in 50%. In practice, we see a nearly ‘sleeping’ head nod. How can we explain this biomechanically, especially as the centre of mass of the head: M lies (far) in front of the pivot point: S. In figure 2-26 we can see that the head must tilt 20° backwards before the centre of mass M is above the pivot point: S.

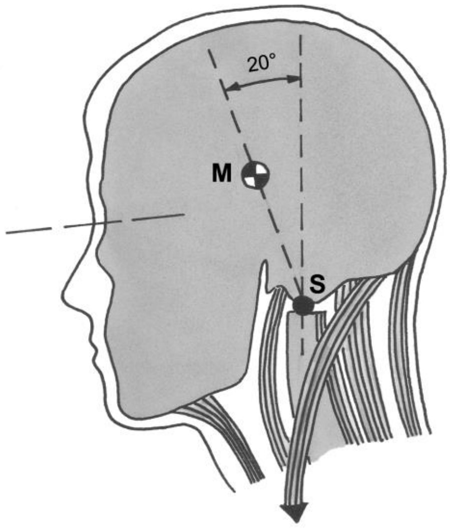


Figure 2-26: Position of the centre of mass: M in relation to the pivot point: S.

If the head is to stay in balance on the trunk with the gaze directed at the horizon then changes of posture must bring about internal forces that bring it into balance. The moment of force (force * perpendicular distance) that the centre of mass of the head M develops in relation to the pivot point S, must be compensated by an equal and opposite moment. The mobility function of the muscles in the neck and shoulder area that position the head in relation to the trunk is extraordinarily complicated, but it is clear that in a certain posture, namely, with an angle($\varphi+\alpha$) of ca.123°, forces occur in the muscles and ligaments of the neck and shoulders due to passive stretching that apparently give the correct opposite moment needed to balance the head and that therefore little or no active muscle exertion is necessary to keep the head in this position.
Not needing to expend any muscle energy in the neck and shoulder area is apparently perceived as being extremely pleasant in view of the fact that this posture is intuitively sought very quickly during activities in which the gaze is on the horizon, such as during conversation. This even happens in chairs that are barely suitable for this as is described in chapter 1.0. Relaxed sitting begins with stability for the trunk and from that point a position is intuitively sought whereby the head is in balance on the trunk and the neck and shoulder muscles can relax.

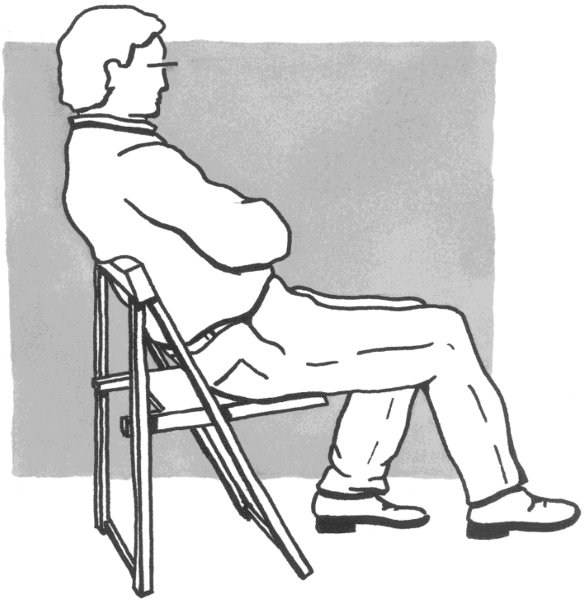


Figure 2-27: An intuitively adopted stable sitting posture with the head in balance on the trunk in a chair that is not actually suitable for this purpose.

The precise size of the angle($\varphi+\alpha$), that will occur, depends on the shape of the spinal column whilst being supported as was shown in the author's own research that was described above, and will be roughly 123º.
Meanwhile, it is evidently clear that the phenomenon 'head in balance on the trunk' will be at the top of the hierarchy of comfort perception.

From these observations it is also clear that the head only finds stability (rest) against a head support when it is tilted at least 20º backwards.

2.5 Stability for the trunk

People's sitting behaviour is, to a great extent, the result of their need not to expend more energy than is necessary. During activities that, because of the necessary hand-eye coordination, demand an active posture, a posture that requires less energy is adopted as soon as the possibility arises. Stability is sought after. The backrest is utilized but the arms can also be brought into action to give stability to the trunk and head. Stability for the trunk appears to be an important determining factor for comfort.

During the author's own research, experiments were carried out using the fitting chair to find out where stability begins, where it stops and what it depends on.
Test subjects were asked to find a posture in which they only just had the feeling that they were sitting in a stable position. The back of each test subject was individually supported according to the procedure described earlier. Stability proved to occur for all of the test subjects at an angle($\varphi+\alpha$) of 115°. The feeling became 'stronger' as the angle($\varphi+\alpha$) increased and that is logical. The experiment was repeated without the individual back supports, that is, with a flat backrest. The results were the same. The measurements were no different when repeated one month later.

In *Sitting Posture* there is a report by Wotzka of the development of an auditorium chair. He tested various chair configurations with a great number of test subjects. In figure 2-28 the profile of the final result is shown. The backrest is 18° out of the perpendicular according to the diagram but according to the definitions of this book (figure 2-15) that is 25°, which gives an angle(φ+α) of 115° and an angle α of 100º. The desktop, that almost touches the abdomen, is at an angle of 15°. In a later version the inclination of this desktop has become 10°.

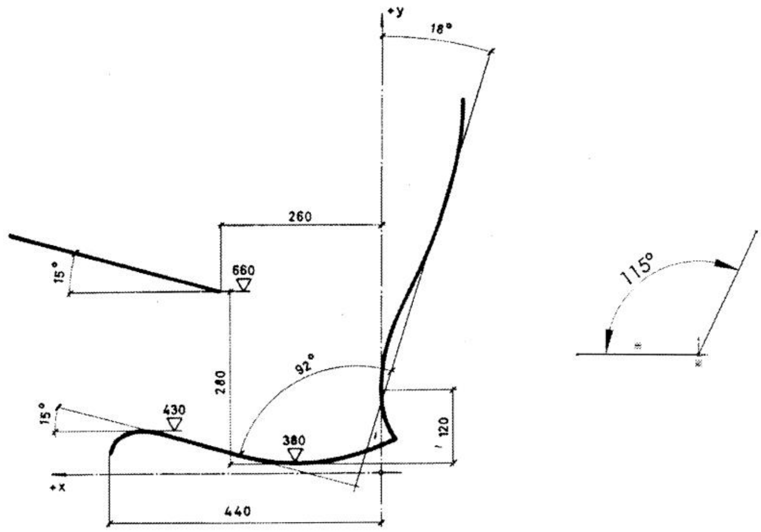


Figure 2-28: Profile and dimensions of the auditorium chair with the angles as defined by Wotzka.

The authors attribute the favourable assessment of the profile of this seating support to the shape of the seat and its relation to the backrest. The curve of the seat allows the body to adopt various sitting positions and eases change of position. The backrest gives support in every posture.

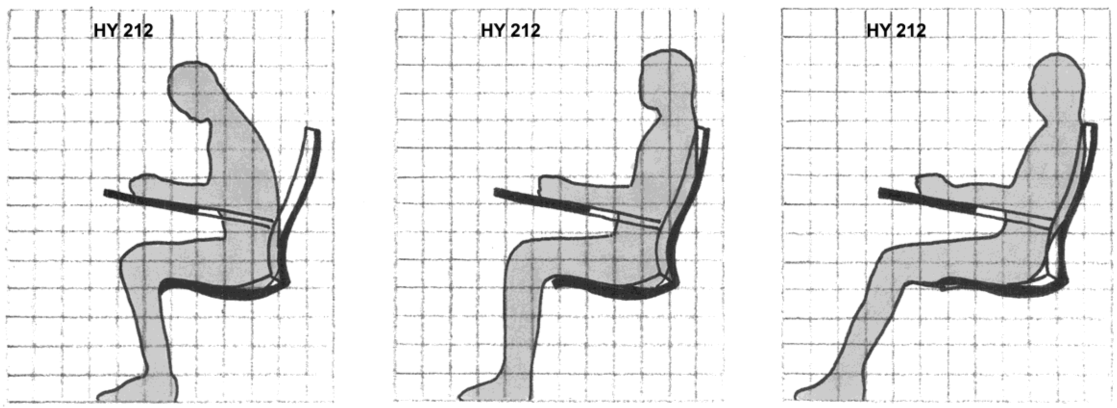


Figure 2-29: The auditorium chair HY 212 with three sitting postures for, respectively, writing, listening and listening with the pelvis tilted slightly backwards as an alternative.

The backrest inclination of 115° is apparently an angle that offers stability when one is only listening but that does not hinder one from leaning forward to write something down. Incidentally, the size of the angle φ plays an important part here. This may not be too great for one to be able to lean forward comfortably with sufficient room for the abdomen and may not be too small to prevent sliding forward in the stable posture. In the leaning forward posture, only the pelvis is supported. Furthermore, figure 2-30 shows that stability does not depend on the position of the ischial tuberosities in the cushion, on the position of the pelvis or on the individual curvature of the back. The position of the pelvis c.q. the curvature of the lumbar spinal column would seem from this to be a possibility for varying the internal load on the spinal column whilst maintaining stability.

The results confirm the observations reached using the fitting chair. Wotzka's results can now be understood better. The most important conclusion is that stability apparently *occurs* with a functional backrest angle: angle(φ+α) of 115° and that this is a universal value.

Stability is easy to understand when a biomechanical model of the human body is used. The modelled pivot in the small of the back plays an important role in this study. Stability occurs or does not occur in respect to this pivot. That depends on the position of the centre of mass of the entire upper body, trunk, head and arms, in relation to this pivot.

Stability occurs when the combined centres of mass of all of the elements of the upper body are positioned above or behind the pivot in the small of the back. In this way an *anatomically sound stability* occurs because the spinal column is burdened in an anatomically sound manner: the total centre of mass of the upper body lies somewhere in the region of the armpit. Figure 2-30 shows a stable and an unstable posture.

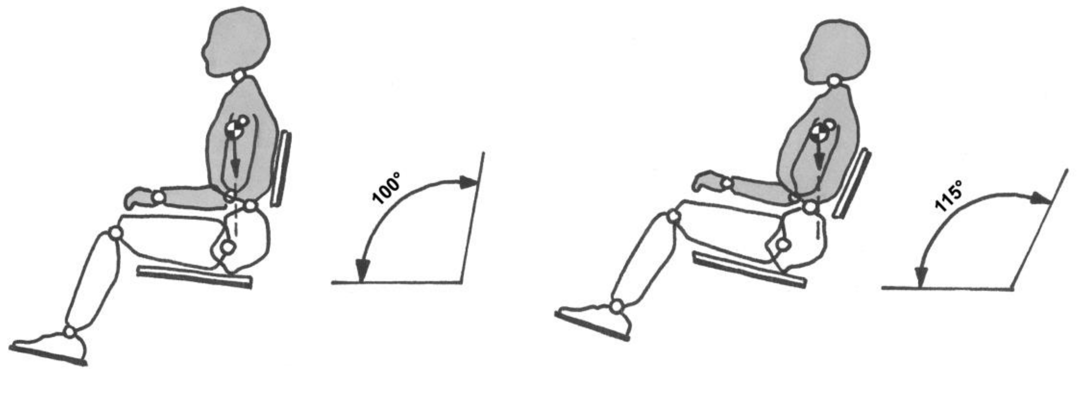


Figure 2-30: An unstable, therefore active sitting posture and an anatomically sound stable sitting posture with resp. an angle(φ+α)=105° and an angle(φ+α)=115°.

In practice, an unstable posture is often 'made' stable by tilting the pelvis backwards, arching the back in kyphosis and letting it 'hang' in the ligaments that hold the vertebrae together. The vertebrae are then in their most extreme position in relation to each other. The pivot in the small of the back is, as it were, locked in a backwards position. The muscles are indeed relaxed, but the intervertebral disks and the ligaments are undergoing extra taxation. Furthermore, the control system in the brain is being misled, as is described in 2.2.2. This sort of stability is anatomically *unsound*.

An exceptional situation arises in the case of an immobile lumbar spinal column. Here the trunk and the pelvis form one inflexible unit. The pivot point for stability shifts down to the ischial tuberosities T. Figure 2-31 shows a stable sitting posture.

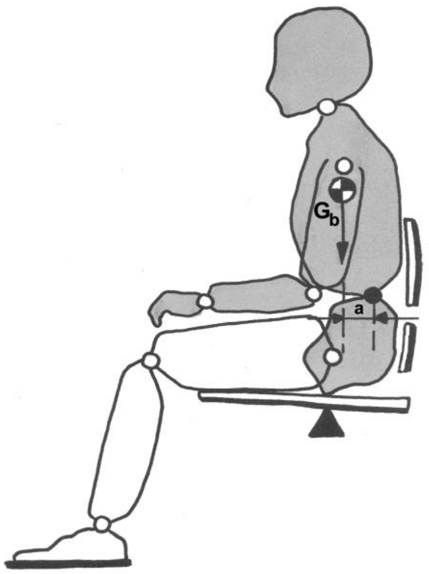


*Figure 2-31: An immobile back in a stable posture with relation to the tuberosities but with an undesirable kyphotic moment of force: Gb * a on the lumbar spinal column.*

All the same, this does not result in an anatomically sound stability. After all, the ligaments of the lumbar vertebrae are under continual extra taxation due to an bending moment of force: Gb * a, where a is the distance between Gb and the pivot point in the small of the back. This leads to further kyphosing of the lumbar region of the spinal column. It also causes more restriction of the abdomen which results in extra pressure on the internal organs. Eventually this is a most uncomfortable experience. To compensate for the kyphosis of the lumbar spinal column, the head has to be lifted more which again, of course, demands extra effort.

2.6 Typification of sitting postures and activities

Every activity creates its own specific posture. The required direction of gaze for the activity is a determining factor here, especially when there is any hand-eye coordination.
Observation of human sitting behaviour shows that people want to expend as little energy as possible on sitting. As soon as a manipulation allows, one seeks stability and tries to find the posture that demands the least energy and that offers the most relaxation, preferably a posture that also gives some relief to the neck and shoulder muscles. This can be achieved by supporting one's head with one's elbows on the table or by finding a posture in which one's head is in balance on one's trunk.

In the analysis and typification of sitting postures, a distinction can be made between active or passive stability of the pelvis, trunk and head.

In table 2-1 the characteristics of all fundamentally different sitting postures are grouped and typified.

A :Active, non-stable posture without pelvis support	**using a pc**	**angle(φ+α) ± 100 °**
The pelvis position is active	the pelvis is not resting on a support	
The position of the trunk is active	the trunk is not resting on a support	angle(φ+α) ± 100 °
Sitting angle		angle α ± 100 °
Seat angle		angle φ = 0 °
The position of the head is active	the head is not resting on a support	angle ε ± 10°-30° *
B: Active, non-stable posture with pelvis support	**eating, using a pc**	**angle(φ+α) ± 105 °**
The pelvis is stable	the pelvis is resting on a support	
The position of the trunk is active	the trunk is not resting on a support	angle(φ+α) ± 105 °
Sitting angle		angle α ± 101 °
Seat angle		angle φ ± 4 °
The position of the head is active	the head is not resting on a support	angle ε ± 15°-35° *
C: Semi-active, stable posture	**using telephone, eating, talking**	**angle(φ+α) > 115 °**
The pelvis is stable		the pelvis is supported
There is an onset of stability for the trunk	the trunk is resting on a support	angle(φ+α) > 115 °
Sitting angle		angle α ± 103 °
Seat angle		angle φ ± 12 °
The position of the head is active	the head is not resting on a support	angle ε ± 25° - 40° *
D: Relaxed, stable preferred posture **	**watching tv (driving a vehicle)**	**angle(φ+α) ± 123 °**
The pelvis is stable	the pelvis is resting on a support	
The trunk is stable	the trunk is resting on a support	angle(φ+α) ± 123 °
Sitting angle		angle α ± 105 °
Seat angle		angle φ ± 18 °
The head is in balance on the trunk	the head is not resting on a support	angle ε ± 35° - 50° *
E: Stable resting posture (with headrest)	**resting, sleeping**	**angle(φ+α) > 123 °**
The pelvis is stable	the pelvis is resting on a support	
The trunk is stable	the trunk is resting on a support	angle(φ+α) > 123 °
Sitting angle		angle α > 105 °
Seat angle		angle φ > 18 °
The head is stable	the head is resting on a support	angle ε ± 15 - 35° ***

*) Depending on the extent of thoracic kyphosis
**) The posture that people adopt if asked to choose when their back is individually supported
***) The head is tilted backwards at least 20° to lean on the headrest

Table 2-1: Typification of sitting postures and activities.

Consistent with the biomechanical model of the human body that has been used; a seating support may consist of a seat with a pelvis support that prevents the pelvis tilting backwards but does demand an active position in the trunk, or a seating support that consists of a seat with a backrest that supports both the pelvis and the trunk.

Stability of the trunk occurs when the lumbar-thoracic section of the back support has an angle($\varphi+\alpha$) of at least 115º.

Relaxation of the neck muscles occurs in a posture in which the head is in balance on the trunk and that is in the vicinity of the defined backrest inclination, angle($\varphi+\alpha$) of 123º.

2.7 The influence of the seating support on the perception of comfort

Earlier in this chapter, sitting posture was described as the source of the external load on the body. Posture is responsible for the magnitude and the direction of the load on the buttocks and on the back. If frictional forces are necessary to maintain the equilibrium of forces, then the ratio between the seating angle, angle φ and the backrest inclination, angle α is not correct.
With a good sitting posture, there are no frictional forces. To put it another way: a sitting posture can be qualified as correct when frictional forces are absent from the equilibrium of forces.
For all clarity: a cushion or the properties of a cushion cannot cancel out frictional forces, even though some producers of wheelchair cushions claim otherwise.
So, a sitting *posture* determines the magnitude and direction of the load, the seating *support* is responsible for the distribution of that load over the body. In the case of a cushion, the term pressure distribution is often used. A cushion with good pressure distribution is experienced to be comfortable. What exactly happens when the pressure is distributed?

Apart from the pressure distribution, the moisture and heat regulating properties of a cushion are also important determining factors for comfort. Just think of how unpleasant long car journeys can be if the moisture regulating properties of the car seat and backrest are not sufficient. One gets very clammy.

A seat also reacts to the dynamics of the movements of the upper body. A seat that reacts strongly is experienced to be wobbly and uncomfortable. In this event the seat gives little lateral stability to the pelvis. These properties of a seat or a cushion are called the *seating stability*. Bad seating stability makes activities that require good hand eye coordination more difficult. The more stable the seating, the easier it is to pursue these activities.

2.7.1 Pressure distribution

When a person is sitting, the weight of the upper body is conveyed down the lumbar spinal column into the pelvis and then transferred via the ischial tuberosities and a thin layer of soft tissue to the seat. The seat reacts with a reactive force that is equal to the total weight of the load on the seat. This reactive force is the load on the buttocks.

This load is seen to be unevenly distributed across the buttocks. In figure 2-32 a general pattern of this distribution has been included as can be measured *between* the buttocks and the seat: the so-called 'interface pressure'.

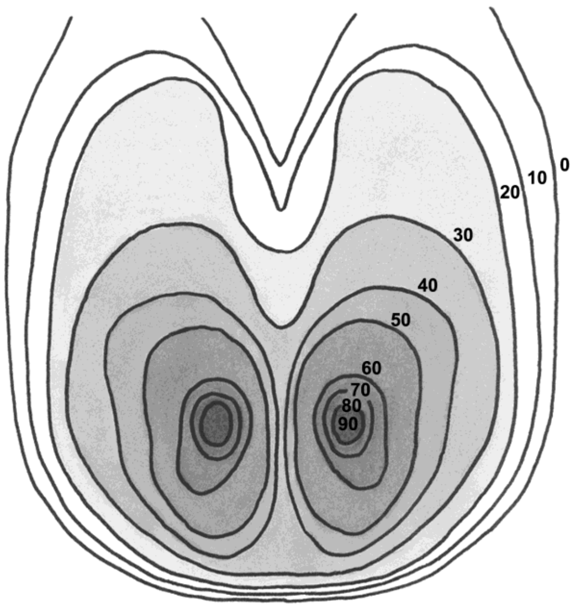


Figure 2-32: A typical pattern of pressure distribution across the buttocks showing that the interface pressure is highest under the ischial tuberosities and decreases towards the outer edges.

This pattern is characteristic and is found in all experiments. The highest pressure is always observed under the bony protrusions in the buttocks, the ischial tuberosities.

The term 'pressure distributing' as the property of a seat should in this connection be taken as follows: the distribution of the reactive forces of a seat across the buttocks shows a pattern of pressure contours around the ischial tuberosities with the pressure decreasing from the middle outwards. A seat is experienced as being comfortable if the pressure on the ischial tuberosities is relatively low. A seat with good 'pressure distributing' properties will try to reduce the pressure under the ischial tuberosities as much as possible. This is partly done by distributing the load over as great an area as possible. Pressure is, after all, the force per unit of area, so the more area there is for the same force, the lower the pressure. As well as this, specific cushion properties can also help to keep the pressure at the position of the bony protrusions as low as possible.

Individual characteristics play an important role in the perception of comfort. It is important to realise that the soft tissue of the buttocks function as a pressure distributing medium in relation to the bony protrusions and that internally the pressure between the bony protrusion and the soft tissue is greater than the pressure below that between the soft tissue and the skin. It all depends on the thickness of the layer of soft tissue. To put it simply: the rounder the buttocks, the less pressure on the bony protrusions. The thickness of the layer of soft tissue between the ischial tuberosities and the cushion and the size of the area that can support the load play a decisive role here. This can be called the *personal pressure distributing capacity* of the buttocks. This capacity proves to be optimal when the shape of the buttocks is maintained as closely as possibly when the buttocks are loaded. Because when the shape is maintained the critical layer between the bony protrusions and the skin is at its best thickness.

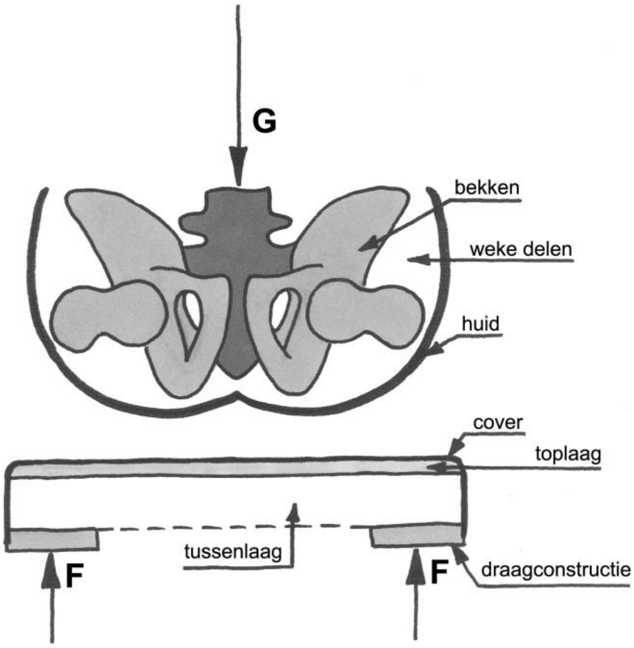


Figure 2-33: A comparable structure of buttocks and cushion with great morphological differences between the hard structures.

It is of great importance to know that the internal pressure under the ischial tuberosities is 2 to 3 times greater than the measured interface pressure. Research in vivo and the author's own investigation (see D 3.0)/experiments with cushions have shown this. A recorded interface pressure value can therefore not be compared with the blood pressure at the point of measurement. What may be assumed is that a reduction of the interface pressure will also result in a reduction of the internal pressure.

A cushion is usually built up from a support construction with a layer of foam as pressure distributing medium and a cover. In popular parlance, a cushion is a fabric bag filled with a pressure distributing medium such as, for example, foam pieces.
But this loose cushion cannot work either until it is laid on top of something. The load must, after all, be conveyed through to a frame that is standing on the ground.
The shape of the support construction (under load) is shown to be of great influence on the resulting pressure distribution when a layer of foam is used. The more the supporting construction resembles the shape of the buttocks, the greater the pressure distributing capacity becomes.

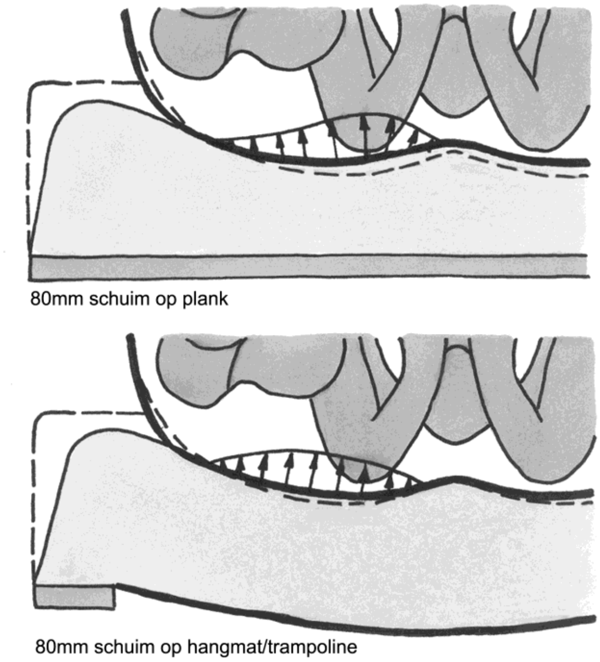


Figure 2-34: Influence of the support construction on the amount of distortion of the foam and therefore on the magnitude of the reactive force of the foam.

In that case, the foam does not need to distort so much and the pressure distribution is better. This is easy to understand if one realises that the foam is in fact a sort of compression spring: The deeper one presses the foam down, the greater the resistance and therefore the reactive force. On a flat support construction, the deepest distortion is under the ischial tuberosities and that is precisely the point at which one wants to have as little reactive force as is possible. If the support construction is given the shape of the buttocks, then not only is the burdened surface increased but the foam hardly has the need to distort. That is all to the advantage of the pressure under the ischial tuberosities. Furthermore, in this way the personal pressure distributing capacity of the buttocks is also used efficiently as the shape of the buttocks is maintained as closely as possible under load.

An old-fashioned tractor seat derives its pressure distributing effect purely from the shape of its support construction and anyone who has ever sat on one knows that, in spite of the lack of a soft cushion, it is really quite comfortable.

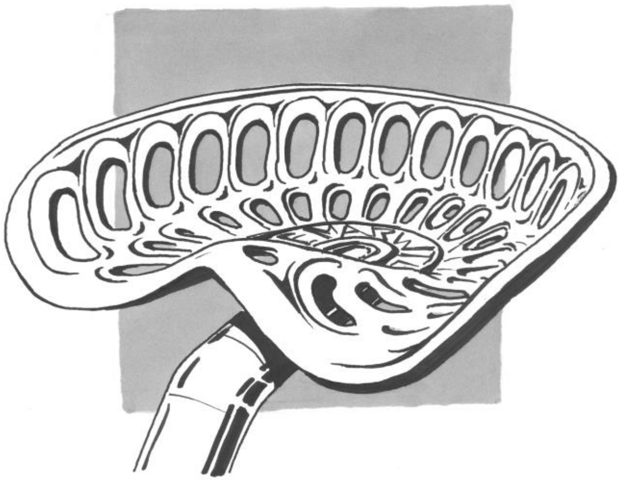


Figure 2-35: An old-fashioned tractor seat: a support construction in the shape of the buttocks for a good distribution of pressure and holes for good moisture and heat regulation.

In many chairs the difference between a well-profiled and a flat support construction can easily be felt because they are barely, if at all, upholstered.

Apart from the shape of the support construction, the quality, rigidity and the thickness of the foam also play a role in the final pressure distribution result.

As well as the various sorts of foam, polyether, latex and the like, there are also other pressure distributing media and systems with the same aim in mind: the best possible distribution of the load on the buttocks for the improvement of the perception of comfort.
In sofas and armchairs, elastic webbing or no-sag springs are often used as support construction. The quality of their effect can be judged by the shape that they take on under load: the more resemblance this has to the shape of the buttocks, the better the pressure distribution.
An interesting pressure distributing medium is the one based on rubberised horse hair or coconut fibre. This pressure distributing medium has a very open structure that is beneficial for its moisture regulating properties.

2.7.2 Seating stability

A seat that provides stability ensures that the top of the pelvis stays more or less horizontal when there is any sideways movement of the upper body. That means that the pelvis forms a stable basis for the spinal column. The effect of this is that the head can keep its orientation on its task or a computer more easily. A seating support should, in this context, not only be seen as a means of creating a suitable sitting posture for a certain activity, but also as a supporting surface upon which forces necessary for performing actions can be applied. The stability of this supporting surface and the resulting lateral stability of the pelvis increase the confidence and the precision of actions and therefore reduce the effort needed to carry them out.

Earlier it was pointed out that chairs in workplaces and offices often have very little or no upholstery. This has everything to do with the need for seating stability. A thick layer of foam will usually give a better distribution of pressure, but will also give reduced seating stability.

On this theme, the office chair with adjustable height that can easily turn on its central vertical axis should be discussed separately as this 'solution' gives a particular sort of instability. It is clear that this chair cannot function as a stable supporting surface because of the permanent rotation capacity of the seat. The reactive forces caused by setting one’s feet on the floor and sometimes also of resting one’s arms on the desktop should be conveyed through the rotation axis of the chair and should then be in equilibrium with each other because the rotating seat cannot deliver a moment of force (force * perpendicular distance) as reactive force. In practice this means that when the upper body is given one-sided support, during which the reactive forces are not conveyed through the rotation axis, the torsion moment has to be provided by the lumbar spinal column. Because the reactive forces change continually during actions, this involves continual correction. This is not only tiring for the lumbar spinal column, but also for the orientation of the head on the on its task. Furthermore, this leads to unnatural sitting behaviour as any normal movements nearly invariably result in extra movements that are not normal. It is hardly possible to shift one’s buttocks in relation to the seat without first lifting oneself up from the seat completely. This does not conform with normal sitting behaviour where one can shift around on the seat to vary one’s posture and the load on one’s buttocks.

The influence of the rotating seat on natural sitting behaviour has never been researched. It is easy to imagine that the instability as analysed above could be the cause of many physical complaints that are now exclusively attributed to incorrect sitting posture behaviour.

2.7.3 Moisture and heat regulation

When people have to sit for long periods, not only pressure distribution but also the moisture and heat regulating properties of a seat cushion are important phenomena in determining comfort.

Depending on the temperature of the surroundings and what one is busy doing, one produces a certain amount of heat, mainly due to muscle activity. This heat has to be lost in some way in order to keep one's internal temperature at a constant value. The difference in temperatures creates a dry flow of heat between one's body and one's surroundings. The size of this current of heat depends on the difference in temperature and on the heat insulating properties of the layers between the skin and the surroundings. This flow of heat is also influenced by ventilation and the air currents around the body. Humans have the capacity to vary their skin temperature within certain limits, in order to alter this heat flow. As well as this there is always a certain amount of moisture given off by the skin. This moisture usually evaporates and, if possible, passes out through the clothing. The evaporation energy is taken from the skin and in this way causes a cooling exchange of heat. The amount of moisture that passes through the skin can be increased so that extra heat may be lost. If the moisture that passes through the skin cannot be dispersed quickly enough, then the moisture will stay on the skin to form sweat. This happens, for example, if the water vapour permeability of the layers between the skin and the surroundings is too low.

Moisture and heat regulation are clearly linked to each other. If one sits on a cushion with high heat insulation then one's body heat will not be properly dissipated and as a result one will begin to sweat. This moisture must be able to evaporate through the seat or be removed. If this does not happen, liquid moisture will build up between the seat and the skin. Conversely, a cushion with good moisture regulation will remove heat along with the moisture.
Good moisture regulation, therefore, has double advantages!

2.8 Summary and conclusions

A sitting posture is defined by the position of the body parts in relation to each other and their collective position in space. Characteristic for a sitting posture are the position of the trunk in space, angle($\varphi+\alpha$), the position of the trunk in relation to the thighs, angle α and the position of the thighs in relation to the horizontal, angle φ. The definition of the position of the trunk in space used here is crucial in this approach as this is the only definition that is biomechanically relevant: the position of the trunk is measured along the lumbar thoracic transition segment *above* the lowest point in the small of the back. With this definition, the position of the trunk in space stands irrespective of the individual shape of the small of the back.

People clearly adapt their sitting posture to the activities they undertake. When these activities demand a direction of gaze that is more or less horizontal and no motory power has to be applied, such as for example, conversing, using the telephone and the like, then stability in posture is sought almost immediately. People are continually trying to find a posture that demands as little expenditure of energy as possible and that feels comfortable. A stable trunk and the 'position of the head in balance on the trunk' prove to be overruling factors in this.
Results from the author's own research show that stability of the trunk occurs at a functional backrest angle: angle($\varphi+\alpha$) > 115° and that this is irrespective of individual characteristics. The same holds for the relaxed individually preferred posture where the head is in balance on the trunk. The final result for that lies within just a few degrees of angle($\varphi+\alpha$) = 123°. An individual back support is a condition here. In the individually preferred posture the neck and shoulder muscles can relax. This aspect is high in the hierarchy of the perception of comfort and is readily observed.

The position of the head in balance on the trunk is the neurophysiological reference position. With the head in this position the body can be most accurately controlled during activities, because one has learnt to do things this way, or, in other words, that is the way the brain has been programmed.

The results of the author's own research into sitting are confirmed by the results of thorough research carried out in 1969 and reported in Sitting Posture. The results of that research can, however, now be understood and interpreted more readily. The new, biomechanically relevant definition of sitting posture has contributed to this.

Where stability and the 'head in balance on the trunk' are experienced as being direct determining factors for comfort, the factor time plays an important role in the external load on the body.
Analysis of the reactive forces of the seat on the buttocks show that with a correct combination of the seat angle, angle φ and the sitting angle, angle α, no frictional forces are necessary for the equilibrium of forces. A sound sitting posture can, in this respect, be defined in this way. Frictional forces on the buttocks are perceived to be uncomfortable after a time.

The pressure distributing properties of supporting elements play a role in the way in which the reactive forces are transferred through to the buttocks. Frictional forces can only be avoided by a good sitting posture: they cannot be 'resolved' by the use of a seat cushion.
Reducing the load on the area around the bony protrusions in the buttocks as much as possible, is the essential factor in pressure distribution and effectively increases comfort.
In the pressure distribution effect of foam cushions, the shape of the support construction plays an important role. The more the shape resembles the shape of the buttocks, the better the pressure distribution.

Apart from the pressure distribution, the moisture and heat regulation of a cushion are important comfort determining properties.

3.0 Application of knowledge about sitting behaviour

The analysis of human sitting behaviour shows that the 'restlessness' seen during sitting is mainly caused by a conscious or unconscious need to adopt a different posture to make oneself feel comfortable again when this is no longer the case. The old situation with its external and internal loads is replaced by a new one.
The body is, after all, not equipped for continual static loads.
Sitting behaviour results from the need to adapt one’s posture to what one is doing. Enjoying a meal does not only involve bringing food from one’s plate to one’s mouth whilst sitting in an active posture: it also includes pauses for rest or for conversation in between eating. These pauses are immediately used for a change of posture. One seeks a stable posture so that less energy needs to be expended, although dining room chairs often do not afford such postures.

Sitting behaviour usually results from unconscious processes. But, in the prevention of sitting complaints, it helps if the sitting behaviour can be influenced consciously. Realising what is happening when one is sitting is often enough to cause one to influence one’s sitting behaviour consciously. Two aspects are important here: being conscious of the manner of taxation and of the duration of taxation. An active sitting posture must really be an active sitting posture. The muscles in the lower back must be tensed to give the back its natural shape as closely as possible. Then the back is taxed in a way that is anatomically sound and the position of the head does not have to be adjusted using extra muscle exertion.
For some reason there is a prevailing misconception that one should not get tired when sitting. But consider this: it is better to be a little tired and healthy than to end up with (vague) back, neck- or shoulder complaints.
Active sitting postures can easily be alternated with stable postures in which one can relax for a while. This improves the necessary dynamic aspect of internal and external load.

Lengthy use of a sitting posture in which one achieves stability by hanging in the ligaments of one’s back should be avoided for several reasons. Admittedly, this posture demands little energy to maintain, but the intervertebral discs and the ligaments are subjected to more taxation. In this posture the head has to be held up higher and this demands extra energy and can lead to neck and shoulder complaints.
Furthermore, one should realise that the control system in the brain is a self learning and self maintaining system. In order to function properly, it depends on feedback based on correct (read: anatomically sound) (sitting) postures. Only in this way can it work properly and provide good control and warning systems.

Chairs and furniture can be all very good, and good and dynamic sitting behaviour can be encouraged by the good properties of a chair, but this behaviour must mostly be more or less consciously produced by the sitter.
Remember: you can sit unsoundly in a good chair and soundly in a bad chair.

These concepts will continue to form the basis of the discussion of the consequences of our knowledge of sitting and sitting behaviour for various types of chair.

3.1 Human scale

In the observation of sitting behaviour and its analysis, nothing has as yet been said about the influence of the dimensions of chairs and furniture on sitting and sitting behaviour. All our attention has gone to the analysis of sitting posture.
Surprisingly, great consistency was found between very different people as concerns constitution (shape and mobility of the back) and bodily size in differentiated, specific sitting postures.
It is, nevertheless, evident that someone who is 6ft 6inches tall will need a different chair from someone who is 5ft tall – not because of their postures but simply because of their sizes.

Chairs for general use are necessarily suitable for the average user. Designers can, in the case of certain dimensions, ask themselves what is worse for very large or very small users, too high or too low, too wide or too narrow, and base their decisions on this. But in the end it will obviously be a compromise that will affect the individual perception of comfort.

Chairs that are daily used by one particulair person and that are often also used for long periods, such as office chairs and wheelchairs, usually have the possibility of being adapted to an individual seating height or depth. Adaptation of the back support to the individual shape of the back is, as has been shown earlier, highly desirable if not essential.

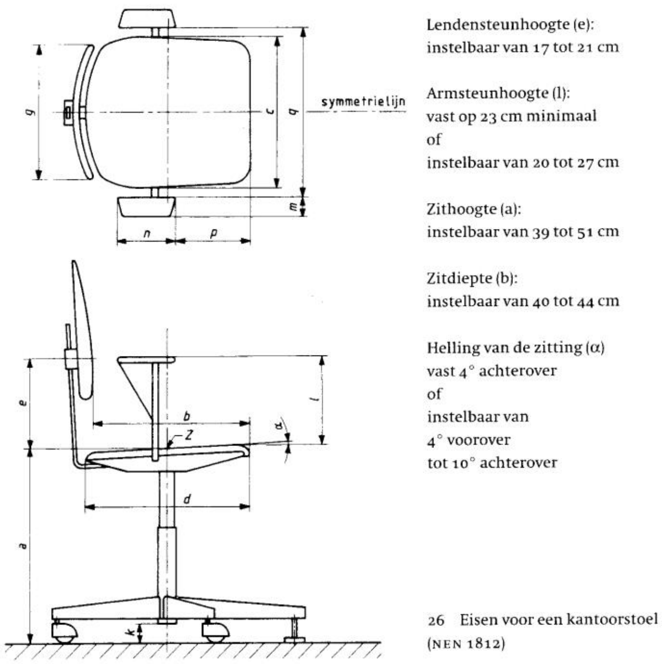


Figure 3-1: Extract from NEN standard 1812, requirements for office chairs in the Netherlands.

The requirements that have to be met in the dimensions and adjustability of office chairs in the Netherlands are laid down in NEN standard 1812. A short extract from this has been included in figure 3-1.

Practical analysis of the dimensions of sofas shows that usually the seating depth is much too deep. This often leads to remarkable sitting behaviour ranging from one leg pulled up under the buttocks to undefined juggling with cushions.

In this book the problematic(s)/question of dimensions in connection with the various types of furniture will not be discussed in any more depth.

3.2 Active chairs

Active chairs are intended for use while carrying out active tasks usually involving hand eye coordination. They may be workplace chairs, dining room chairs or even office chairs.

In the analysis of sitting behaviour on this sort of chair it is soon clear that the pursuit of tasks in an active posture never continues for 100% of the time. Shorter or longer rest periods are always observed in between the tasks. The rest periods are used to relax the body. During these rests people change their posture and seek stability.
Strangely enough these chairs are often not suitable for this. The backrest usually does not have a shape or inclination that renders it suitable for affording stability in any sound or comfortable manner.

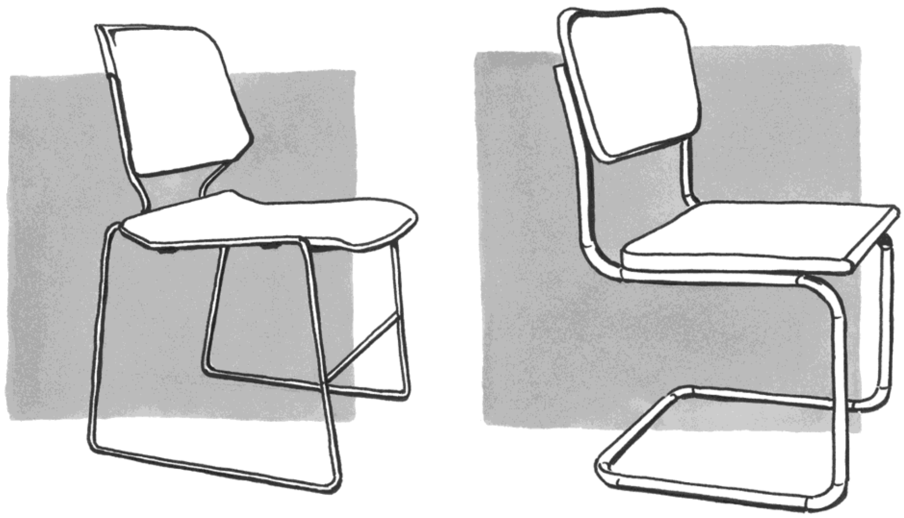


Figure 3-2: Examples of common active chairs: a stackable office chair and a modern plastic restaurant chair.

In principle, an active posture does not call for any back support. It is even preferable not to support the back. After all, most tasks require activity in the arms and hands. Muscles in the arms and hands must therefore be used and activated. This cannot be done without including the muscles in the trunk. It is easier to turn it round: for carrying

out precise motory manipulations with the hands and arms, it is necessary that all of the muscles in the trunk are involved and are 'flexed'/have (initial) tension
One needs to realise that, for instance, lifting an object from the table means exerting a load on the back. The greater the weight is and the further the distance from the back, the greater the load. This load has to be actively compensated by the muscles in the back. Groups of muscles cannot be individually activated without involving the other muscles.

It is in order to mention at this point, that the same applies for using the mouse when working with a computer. The loads are indeed not great, but there is call for a top precision manipulation based on a refined control system. This cannot be carried out if the trunk is completely relaxed. The control system in the brain is not equipped for this. Inversely, the control system must be supplied with good 'examples' of postures and movements in order to be able to continue with the precision work. The control system is, after all, a self learning and self maintaining system.

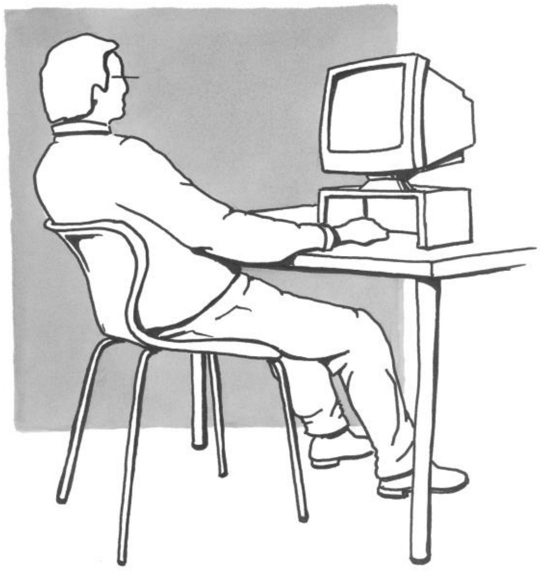


Figure 3-3: Unsound - non-active - posture on a good chair while working with a computer.

Tasks and manipulations are carried out, and indeed can be carried out, because the control system in the brain has a reference. Earlier we compared this with the function of a spirit level in the construction of a house. Manipulations become more complicated, from a motory point of view, when they result in movements that were not intended. This applies not only for the control system but also for the motory system. Manipulations carried out in a sitting posture are indeed most precise and also easiest if they are undertaken from a stable basis. A seat should be such a stable basis. Swivelling seats in office and work place chairs are not stable. They have a counter productive effect and came into use in the time of the first electric typewriters with a typeball as these had extremely high keyboards. In order to use them properly one needed a low-level desktop. In those days a good desk consisted of a desktop at the normal height and a small section at a much lower level for the IBM typewriter at right angles to it. In this configuration a chair on castors with a swivelling seat seemed to be very sensible. Moreover, the central vertical axis can easily be made adjustable in height, and then,

extra measures have to be taken to prevent it from swivelling. It was therefore an easily reached solution.
Nobody gave any thought to the consequences of this solution for sound sitting behaviour. A swivelling seat was made compulsory for desk chairs in the Netherlands in the NEN 1812 standard.

Figure 3-4: Typist at work in the 1970s Bron:Vincent Mentzel/Hollandse Hoogte

On the basis of the discussion above, this sort of office chair should actually be forbidden instead of being recommended by safety and work inspectors backed up by standards such as those of NEN in the Netherlands!

Active sitting postures have a seating angle that is almost horizontal. This has to do with the space that has to be created for the stomach and with the fact that in a truly active posture without the use of a backrest there are no frictional forces between the seat and the buttocks. As an active posture has priority in this sort of chair and therefore the seat will be almost horizontal, leaning backwards in a stable posture will necessitate frictional forces in the seat to bring about an equilibrium of forces. Earlier we discussed the fact that frictional forces are not initially experienced as unpleasant, only after a period of time do they give discomfort. The compromise chosen in the concept of this chair is therefore acceptable. However, the seating surface must be rough enough for a frictional force to actually be realised so that the user does not have the feeling that they are going to slide off of the seat each time stability is sought for the trunk by using the backrest.

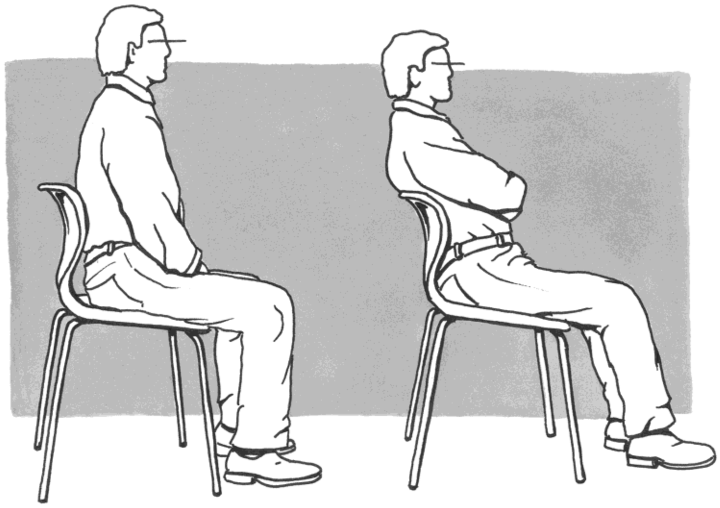


Figure 3-5: Example of an active sitting posture and of a stable posture on one and the same chair. In the stable posture, friction is necessary on the seating surface.

3.2.1 Office chairs

Office chair is a general name given to a chair that can be used in many different ways. As the use of these chairs is not limited to one particular person, the dimensions are suitable for the average user. The seat and backrest may be upholstered but they may also be of non-upholstered wooden or plastic components that are usually contoured to some extent.

Office chairs are used in meeting rooms, where most of one's time is spent listening and occasionally making a few notes on paper or laptop. Alternatively one may be looking at a screen to follow an audio-visual presentation. Here the chairs are usually lightly upholstered and fitted with armrests.
The length of time one sits on such a chair can vary from half an hour to as much as 3 or 4 hours with a short break.

Office chairs are also used a great deal in rooms where lectures are given. The only activities that one then undertakes are listening and watching. An average period of use here will easily be at least 45 minutes.
Often, in this case, the chairs are not upholstered and have a fairly flat seat. Whether they have armrests or not depends on the luxury of the surroundings. For practical reasons these chairs can often be stacked.

In canteens or company restaurants one often finds these chairs.

Nearly all designs of office chair afford an active sitting posture. They do not usually afford the possibility of varying one's posture with an anatomically sound, stable posture even though most of the time one uses them is spent listening.

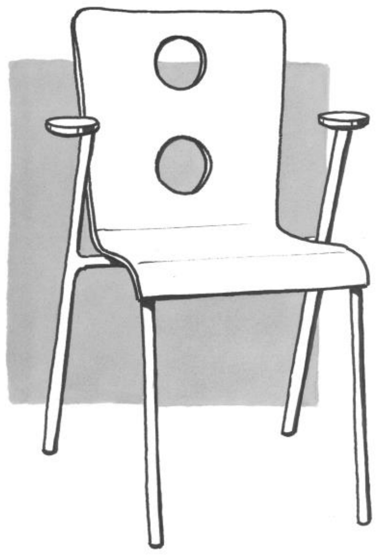


Figure 3-6: Office chair with an active sitting posture without the possibility of a posture with anatomically sound stability.

People, however, try to find such a stable posture in some way or other even when using one of these chairs that does not really afford these postures. One can try to find enough space and support, for example in the angle between the backrest and the armrest, in which to lean one's trunk a bit further back.

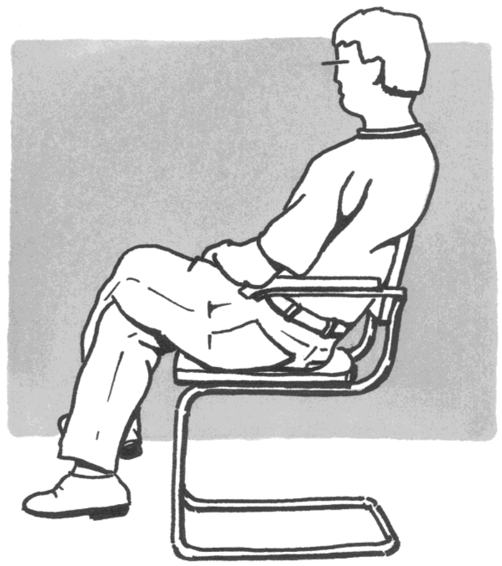


Figure 3-7: Seeking space for a stable posture in the angle between the armrest and the backrest.

Or one can slump down and balance one's trunk on the top edge of the backrest.
Not only is there a need for stability for the trunk, there is also a need to relax the neck and shoulder muscles. One tries, if one is seeking a posture anyway, to bring one's head into balance on one's trunk while one is sitting down to listen.

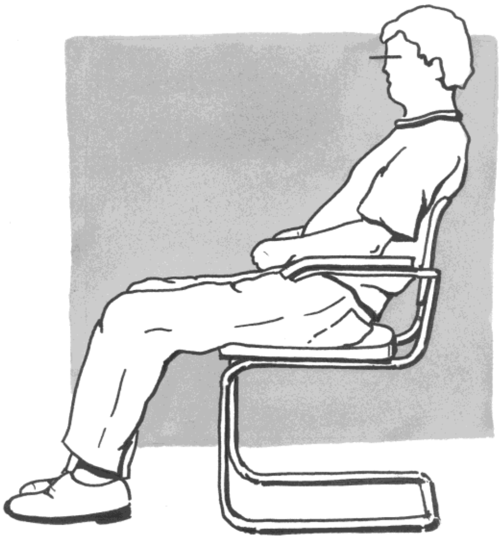


Figure 3-8: In an active chair, trying to find a stable posture with one's head in balance on one's trunk by slumping down and actively keeping the small of the back 'in shape'.

In view of the functions actually given to office chairs in practice, each design should afford an anatomically sound stable posture. That is to say, the chair should have a functional backrest inclination, angle(φ+α) of at least 115º.

Figure 3-9: A good example of a chair for dining room or office is DD 04, a design with an functional backrest angle: angle(φ+α) of 115º.

In view of the usually extended average period of use, an office chair should have a profiled seat to improve its pressure distribution properties. An upholstered seat should have a profiled support construction as this increases the seating stability. Obviously, a fabric that allows water vapour to pass through will improve the moisture and heat regulating properties of the cushion.

In principle, a good office chair could offer all of these possibilities. There are no technical obstacles. It is all a matter of knowledge of how such a chair is actually going to be used and what the consequences of that usage are.

Figure 3-10 shows one solution: a plastic office chair with a profiled seat and a backrest over which it is possible to, as it were, unroll one's back. In this way one can easily find a comfortable posture.

Figure 3-10: Office chair with profiled seat and a backrest that follows the contour of the back for an anatomically sound stability.

The front edge of the seat is well rounded to prevent the blood vessels becoming obstructed when one stretches one's legs or if the user has far longer or shorter lower legs than average.

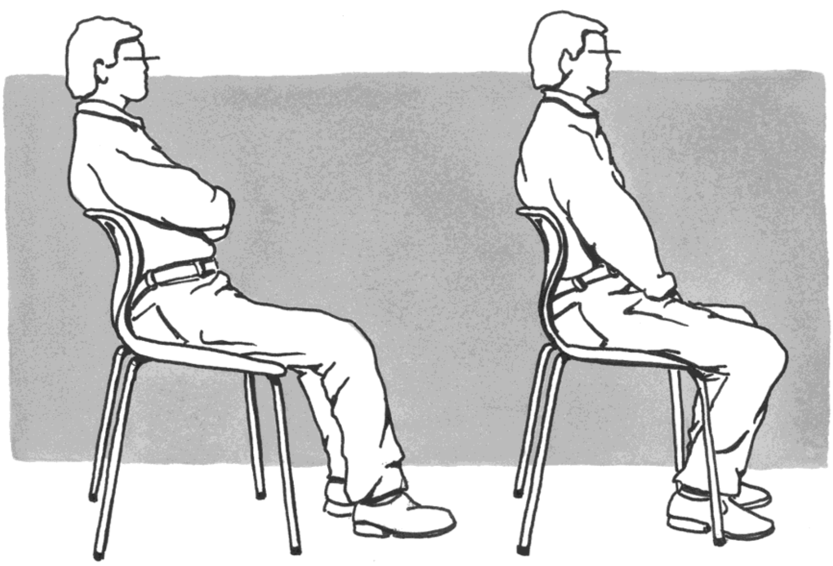


Figure 3-11: Back support following the contour of the back in different postures.

Various factors play a role at the beginning of the design of an office chair: the materials that are going to be used, production costs, whether they can be stacked, design, image, and so on. None of these factors can or may ignore the function that these chairs will have for the majority of the time that they will be in use: to afford stability. No single one of these factors need stand in the way of realising this function.

3.2.2 Dining room chairs

A dining room chair is, functionally, an office chair that has been adapted for the home environment. Most of the time spent in these chairs is spent in conversation or looking round and therefore the need is for relaxation, stability.
This is often a far cry from what a dining room chair affords. Design and ambience usually influence the customer's choice far more than functionality.
As so many ambiences can be defined, from romantic country cottage to stark and modern and everything in between, the market offers just as many different dining room chairs. Design and ambience play an even greater role in their design than is the case with office chairs. There one can still detect some sort of realism. That is no longer present in the design of dining room chairs.
'Design' is taken so far that the most impossible chairs are not only produced but are also sold.

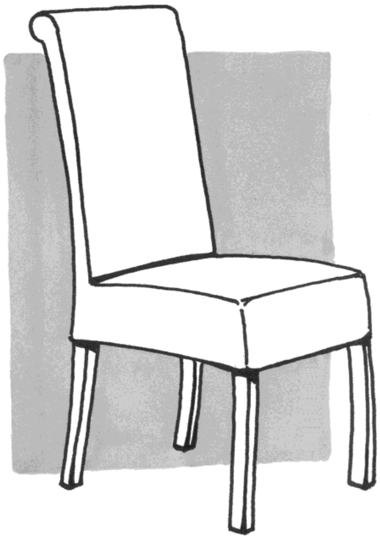


Figure 3-12: Dining room chair in trend in 2005 with an active sitting posture and without the option of improvising any stability other than anatomically unsound stability.

The trend in 2005 prescribed colonial-style wickerwork chairs with a backrest that was almost perfectly vertical and reached some way above the shoulders. The only possible anatomically sound posture in such a chair is an active posture in which the backrest is not used. Any form of anatomically sound stability is impossible to realise.

Even in the well-known and exceptional design by Arne Jacobsen dating from 1959, the butterfly chair that can be used as dining room chair, canteen chair or general office chair, no anatomically sound stability can be found. The backrest is flat and has an angle of ca. 100º, and no space has been created for the buttocks: the support surface of the backrest intersects the seat at the back. The seating angle is ca. 3º. The front edge of the seat and the top edge of the backrest are not rounded but sharp.

Figure 3-13: Butterfly chair by Arne Jacobsen affords an active sitting posture.

The remarks directed towards this chair can be directed at a great number of dining room and office chairs.

The well-known folding chair in figure 3-14 dating from the 1960s certainly only offers a limited support surface for the back but because the trunk is then supported just above the small of the back and there is space for the buttocks, the user can find anatomically sound stability by positioning their trunk above the backrest.

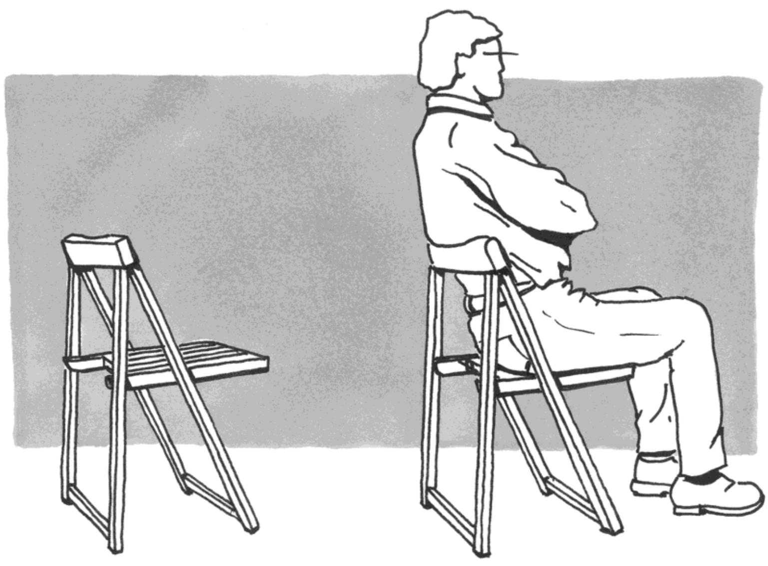


Figure 3-14: Finding stability for the trunk on a low backrest by positioning the trunk above the backrest.

Many dining room chairs with a relatively low backrest allow the possibility of positioning the trunk more or less above the backrest in order to find stability. After a while, however, the higher pressure on the back caused by the small support surface will cause discomfort.

3.2.3 Work(place) chair

The primary function of a work chair is that one can work in it. Working whilst in a sound sitting posture implies total activity in the upper body in an active posture. Here, support for the back is neither necessary nor desired: conscious, and therefore correct, sitting behaviour is. The best hand eye coordination can be achieved from a stable basis: a seat that cannot rotate or move at any moment.
A lot of work is done on stools that can be adjusted in height and have a well-rounded, curved seating surface. The seating surface is stable and cannot rotate.

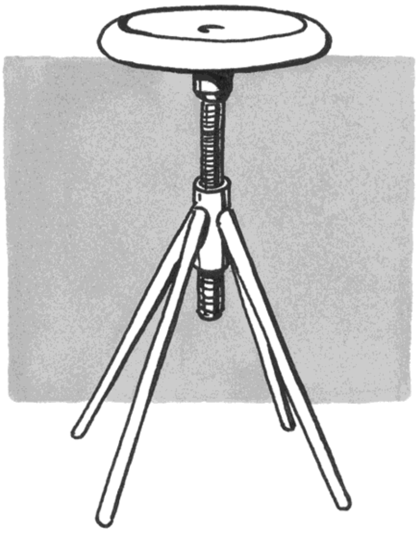


Figure 3-15: Stool with profiled seating surface and adjustable height.

The so-called balance stools are an assault on the knees. The legs have to actively generate stability to give a stable basis in the pelvis for the movements of the trunk. The knee joints are the weakest link in this process as they are not suitable for this sort of stress/loading. Serious knee complaints are the ultimate result. Figure 3-16 shows clearly why one *cannot* work on such a stool.

Other versions of such stools have a 'moving seating surface fitted with a rubber joint that follows the movements of the body in 3 dimensions'. Quite apart from the fact that it is questionable whether this property serves any purpose, the text is misleading.

Figure 3-16: Demonstration of a 'balance stool' in an advertisement.

The seating surface of this stool does not follow the movements of the body, but the body exerts an extra load to the left or the right to move the seating surface to bring about an unstable equilibrium from which to carry out manipulations. What would appear to be a positive property is in fact a negative one.

Stools on wheels should be used as little as possible for similar reasons. These stools can never give a stable basis if the work demands horizontal exertion of force.

One exceptional category of work chair is the stand support or sit-stand chair.

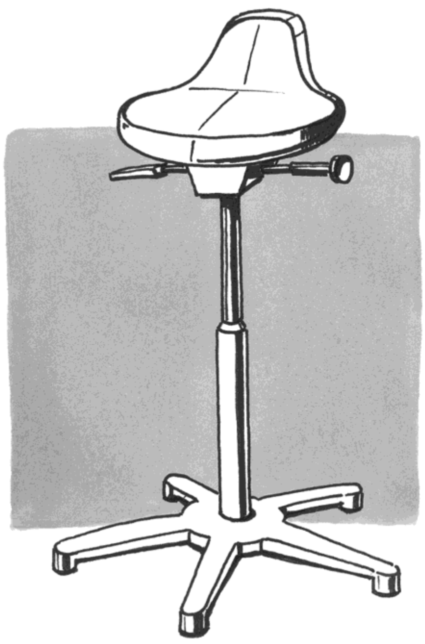


Figure 3-17: Sit-stand seating.

The sit-stand chair creates a sort of compromise between standing and sitting: it is half standing and half sitting. It lends stability to the standing posture whilst the knee and hip angles remain in the comfort zones of these joints. The position of the pelvis automatically forces the lumbar section of the spine into its natural curve. This results in anatomically correct loads on the spinal column. The load on the knees is less than in a standing posture but more than in a normal sitting posture. The load is, however, exerted in the correct manner. The use of a stand support encourages good 'sitting behaviour' and gives more elbow room, both literally and figuratively speaking. Obviously, the seat should not be able to rotate or tip and the column should not be able to lean or otherwise the solution is worse than the problem. '*Flexible sitting thanks to the column that can lean up to 10º*' is functional in only a very few situations. And a *Body Balance Sit system* that follows all of your movements can only really be functional in a very few instances.
The shape of the seat should be a cross between a saddle and a seat as such a shape offers more grip for the buttocks.

Many stand supports are used in situations in which the working height is higher than the usual height of a table or desktop. For these situations there are also office chairs available on the market with adjustable height and footrests that maintain their relative position.

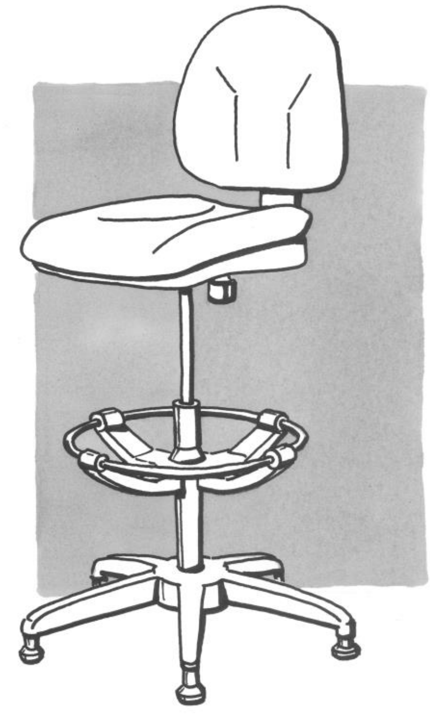


Figure 3-18: Work chair or drawing table chair with adjustable height.

The disadvantage of these chairs is that due to the more or less fixed position of the feet on the foot ring there is very little possible variation in posture, especially in comparison with the alternative, the stand support.

Finally, a few last remarks on the ordinary work chair with backrest. If one is busy with activities or manipulations, these should be carried out from an active posture and involve the whole upper body. The backrest should not be used, preferably not even to support the pelvis. This is a matter of conscious sitting behaviour. One has to consciously choose to sit in this manner. This is the only way to prevent bodily complaints in the long run. In moments of rest there is a need for relaxation and therefore for stability, sound stability. This can be given with a backrest inclination, angle(φ+α) of at least 115º. In fact, this is the same story as with the general office chair.

3.2.4 The desk chair: sitting and working with a pc

Working with a personal computer is a special situation. The fascination can be such that the normal warning mechanisms that indicate that the body is being overly stressed are not noticed. This is where the dangers lie. The creation of a healthy work situation can limit or delay the damage but the best prevention is conscious sitting behaviour: knowing how the various loads on and in the body are and should be distributed and being alert to warning signals. Duration is the all important determining factor here. Change is the keyword. On top of that, the work situation including the position of the screen, the chair used and the planning and varying of tasks can be optimized as far as possible.

In order to force users into a correct, active posture, the centre of the screen should be placed at eyelevel. This does not only encourage active sitting behaviour but also keeps the control system in the brain in order through continual resetting of the references.

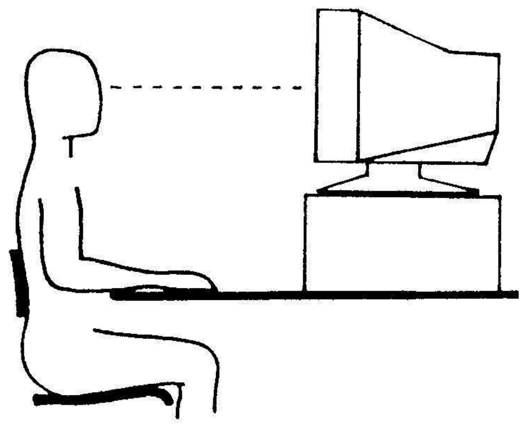


Figure 3-19: A classic situation with the screen at eyelevel and support for the small of the back. Better still, an active posture without support for the small of the back.

Incidentally, in this posture the neck and shoulder muscles are also stressed much less than is the case when one uses a screen at 'laptop level' all day.

As was described earlier, the use of the mouse should be seen as a top precision manipulation which should involve the whole upper body. The posture should therefore be - consciously – active and the backrest should be used only as a support for the pelvis, but preferably not at all.

The remarks made earlier about the seat forming a stable basis obviously apply here as well. *Conscious* movements should not result in any *undesired* movements. That is an assault on the control system in the brain and is unnecessarily tiring for the motory apparatus: so no chairs on wheels or swivelling seats.

An individual seat height and working height is most desirable. People all have (more or less) the same postures but not the same dimensions.

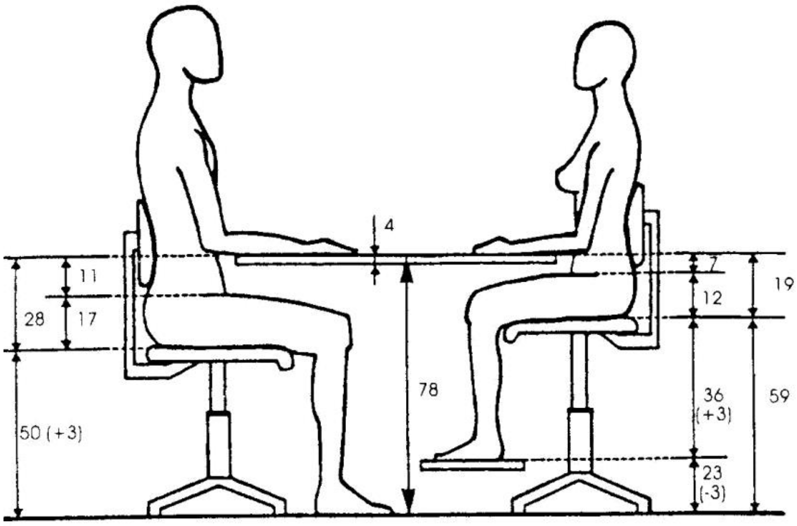


Figure 3-20: A ‘classic’ 90% solution for office furniture, measurements in cm according to Dined, 1986.

Figure 3-20 shows the 'classic' supported working posture as it can be found in the literature but that nobody actually applies. The next representation, in figure 3-21, is a better one. Whether this is applied in practice depends on the extent to which people are consciously aware of their own sitting behaviour.

An active posture will always be alternated with more relaxed postures. This occurs when one stops to think or to make a telephone call or to discuss something with one’s colleague. Good back support allows this as one can ‘unroll’ one’s back over the backrest until one has found stability. As a consequence of the almost horizontal seat, this relaxed posture needs friction forces in the seating surface to bring about the equilibrium of forces. Without these frictional forces one would, after all, slide out of the chair. Earlier it was shown that this load on the body hardly influences the momentary perception of comfort and only leads to discomfort after a period of time. In the assumed use of this chair that is perfectly acceptable.

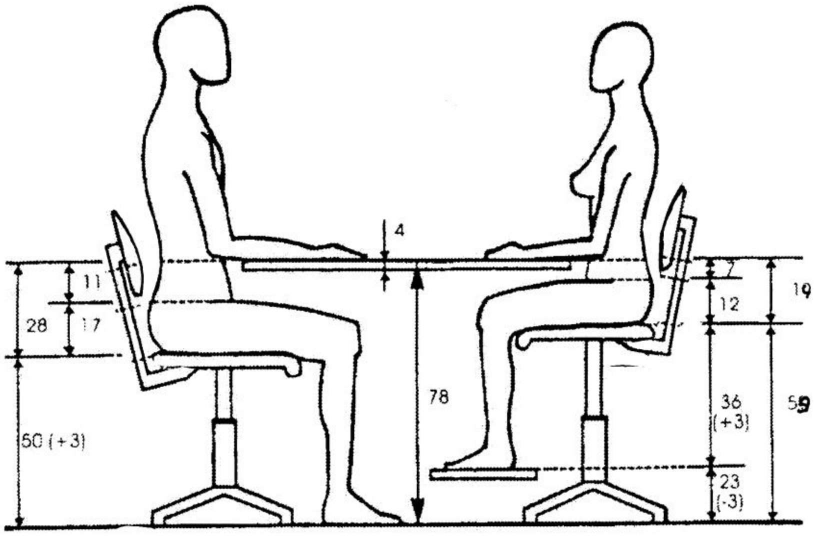


Figure 3-21: Improved version of figure 3-20 in which people are working actively and can relax in a stable posture in between times.

A properly adjusted individual sitting height means that the pelvis can be kept in a correct upright position actively but with very little effort. The position of the pelvis determines the shape of the spinal column above it. A pelvis that is leaning too far backwards flattens the natural shape of the small of the back and causes a greater load at that point. If the height of the seat is too low, the resulting position of the upper and/or lower legs means that more effort is needed to keep the pelvis in the right position. A seat that is slightly too high is better than one that is too low.
A properly adjusted sitting height is an important precondition for good sitting behaviour.

The seating angle is almost horizontal in order to stimulate active sitting. The front of the seat is rounded off so that the seat can be adjusted to a sufficient height without this leading to constriction of the thighs.
The seat is contoured to the form of the buttocks to achieve a better distribution of pressure. The seating comfort will be further improved if the seat is upholstered with a thin layer of foam covered with a material that has a certain ability to regulate moisture and heat.

3.2.5 Kneeling chairs

A totally different way of sitting is afforded by chairs with seats that incline heavily forwards and in a support for the knees to stop one sliding off of them: the so-called kneeling or knee-sit chairs. The idea behind this is that the posture adopted in such a chair with a greater hip angle and the forward inclination of the seat will itself lead to a more natural curve in the lumbar spinal column because the pelvis is more or less forced into a correct position as one sits.

Figure 3-22: Kneeling chair.

Although the idea here proves to be correct to a certain extent, the concept has more disadvantages than advantages. Research shows that, in practice, a better curve is not achieved in the small of the back if the user does not show the correct sitting behaviour. Even though it would cost less effort, the pelvis does not automatically adopt the correct position: one has to consciously want to adopt this position as is the case with any other active chair.

The posture afforded by a kneeling chair leaves very little room for variation or change of posture and leads to a less than comfortable static load on the knees. Sitting down on and rising from a knee-sit chair is usually experienced as difficult.
As is so often the case, here the remedy is worse than the complaint.

A chair with a stable, seat that cannot swivel can also lead to this sort of 'balance posture': one just has to tip the chair forward onto its front legs or to slide oneself forwards to the front of the seat in order to increase the angle at the hips.

Figure 3-23: Balancing posture on a stable chair with a stable support surface as a variation in posture as part of normal sitting behaviour.

3.3 Semi-active and rest chairs

Characteristic for these chairs is the stable posture that they afford or should afford during activities where the direction of gaze is horizontal for most of the time. One converses in an armchair, watches television on the sofa, drives a vehicle or travels by air to distant places spending one's time alternately resting or reading.

The time spent in these seats is usually relatively long. For this reason these seats are intended to offer the user as much comfort as possible.

Unfortunately, the usual practice is to try to achieve this comfort by using (a lot of) soft cushions. This is, however, a serious misconception. Comfort begins here as elsewhere with a good posture in which the trunk is given anatomically sound stability and the head is in balance on the trunk in order to relax the neck and shoulder muscles.

Although these chairs are similar in that the postures that they should afford are very alike, there are in practice a number of observable nuances that will be described in the following paragraphs.

3.3.1 Armchairs and sofas

In an armchair one can watch television, carry on a conversation or read a book.
The most relaxed posture for watching television is an anatomically sound stable posture in which the head is in balance on the trunk: the individually preferred posture. The backrest inclination, angle($\varphi+\alpha$) should be in the order of 123º and there should be enough room from the buttocks in the back support. In short: the profile described

earlier that was developed by Grandjean for people with back complaints is a good general profile for this sort of furniture because is meets the general conditions for sound stability and affords a posture in which the head is in balance on the trunk. Also the relation between the sitting angle, angle α and the seat angle, angle φ is such that no fictional forces will occur in the seat to realise the equilibrium of forces. Under load, the backrest above the small of the back virtually dissects the seat between the position of the bony protrusions in the buttocks and the back of the seat. In this way there is enough space left for the buttocks and to allow for any individual curve of the spine.
In this book, partly as a result of the author's own research results, Grandjean's profile has been promoted to a general basic profile for seating supports that try to achieve a posture with a relaxed position for the head on the trunk. Armchairs and sofas belong to this category and should therefore meet these prerequisites/starting points.

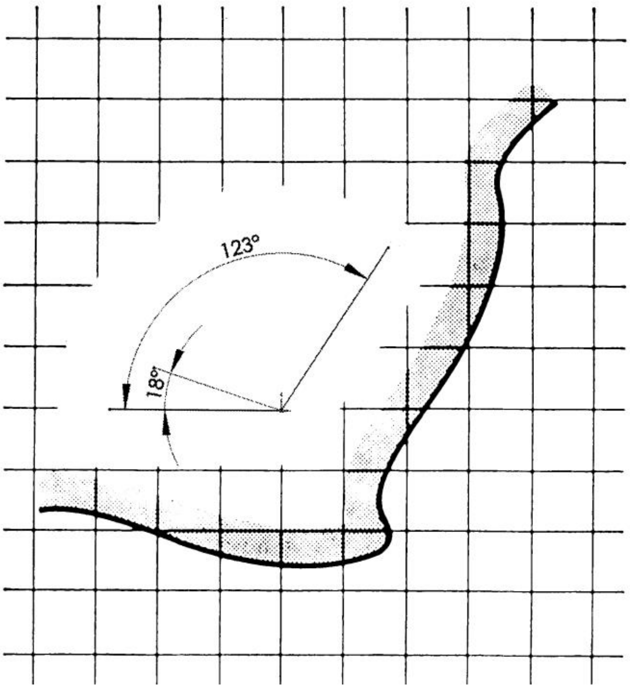


Figure 3-24: General basic profile for an armchair with head support in a 10x10 cm grid according to Grandjean.

The desired angles must, of course, occur under load. This means that in practice as a result of individual differences such as seating weight and seating surface there will be small differences in the posture realised. This depends partly on the basic construction the armchair. A rigid support construction covered with a layer of foam will, generally speaking, come closer to the desired posture than a sprung/elastic support construction in the backrest and seat based, for example, on no-sag springs or rubber webbing.

In the basic profile the head support has been maintained. Of course, not every armchair need have a head support but if one is planned then it should be one like this. As was described earlier, supporting the head when one is actively looking around is pointless. The centre of mass of the head is, after all, 20º in front of its pivot point. Stability can therefore only be found when the head is tilted back 20º and the gaze is directed at the ceiling: when one retreats for a moment and closes one's eyes.
The basic profile allows for this.

In this posture, one's comfort can be increased by the creation of as large a supporting surface as possible. This, after all, gives the lowest - average - pressure. The cross section of the profile should therefore resemble the cross section of the body as closely as possible. The shape of the support construction under load, the quality of the foam used and also the suppleness of the upholstery all play a decisive role here.

The use of cushions in a good armchair is unnecessary and therefore undesirable. It is actually more or less an admission of weakness in the design if cushions are needed to realise a comfortable posture.

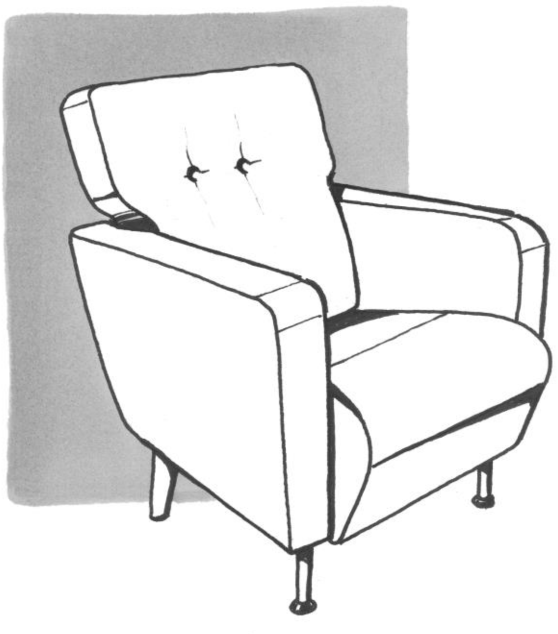


Figure 3-25: Prototype armchair with a seating posture under load according to the general basic profile and with sitting depth and lumbar height that can be individually adjusted to the customer.

The armchair in figure 3-25 has a profiled support construction in the backrest. The shape and construction are shown in figure 3-26. The dark section is the part that supports the central area of the back above the small of the back and forms the basis of the position of the trunk in space.

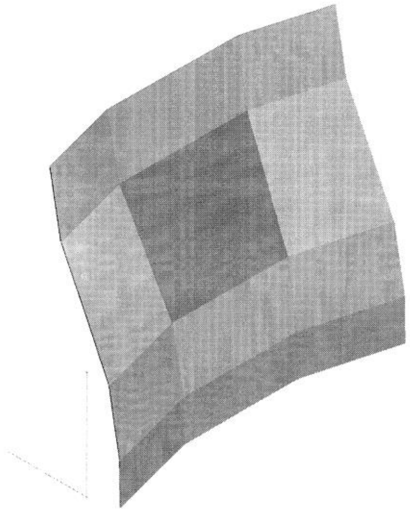


Figure 3-26: Profiled support construction of the backrest of the armchair shown in figure 3-25. The dark section supports that part of the trunk above the small of the back.

The seating surface also has a profiled support construction in the - abstract - shape of buttocks. This improves the distribution of pressure and increases sound/good seating stability.

Good moisture and heat regulation will increase the feeling of comfort even further. If foam is used as a pressure distributing medium, then a top layer with and open structure should be added.

The armrests in the design in figure 3-26 are at the correct height to effectively support the arms. This reduces the pressure on the seating surface and increases the comfort.

Judgement of the seating qualities of an armchair can hardly ever be given just by looking. This depends, after all, on the result of the loads. Design considerations could aim at a certain shape for the empty chair that does, however, give the correct profile and the correct posture under load. A designer could always use very soft foam to realise a certain overall shape that would nevertheless afford a sound posture when sat upon.

The possibility of varying one's posture in an armchair is limited due to the limited amount of space on the seat. A small variation in posture is possible if one turns to sit in the angle between the backrest and the armrest. Often one sees people crossing one leg over the other and later changing their posture by crossing their legs the other way.

It is not absolutely necessary to upholster armchairs with a lot of foam filling in order to create a comfortable seating support. Experience with design DD 07 in figure 3-27 shows that posture is far out the most important issue in achieving a good perception of comfort. In this armchair the various sections of the back that need to be supported are, as it were, marked out by separate supports. The middle section determines the position of the trunk in space. The design was inspired by the designs by Gispen and is a functional commentary upon them.

Figure 3-27: Prototype DD 07 from 2005.

Armchairs with a support construction based on barely elastic webbing have the ability to adapt themselves easily to individual details.

Figure 3-28: Prototype armchair from 2005 with a support construction of woven strips with a backrest inclination, angle(φ+α) of 123º.

Finally, some remarks on getting into and out of a chair. In order to prevent frictional forces in the seat of a chair, the seat will have a certain backward inclination when in use. This can make it difficult to get up out of the chair: elderly people can find this especially difficult. Armrests at the correct height that continue quite a way to the front of the cahir/chair and smooth upholstery on the seat can help to minimize this problem.

3.3.2 Seats in trains and airplanes.

Sitting for long periods of time is not in line with human nature. The body is not built for long periods of static load. If, however, there is no possibility of avoiding it, the conditions must be made as optimal as they can be to provide comfort. Obviously, here also conscious sitting behaviour, or rather a consciousness of 'how and how long one can sit' is eminently important.

During a commercial flight one can read, a meal is served, one can watch television on a small screen straight in front of one or one can try to sleep. The airline does its best to see that one needs as little space as is possible in order to keep the price of the ticket as low as possible. The construction of the seats must be such that their weight is kept down while complying with all manner of safety requirements: truly no small order for a designer. Here the focus is strictly on functionality.

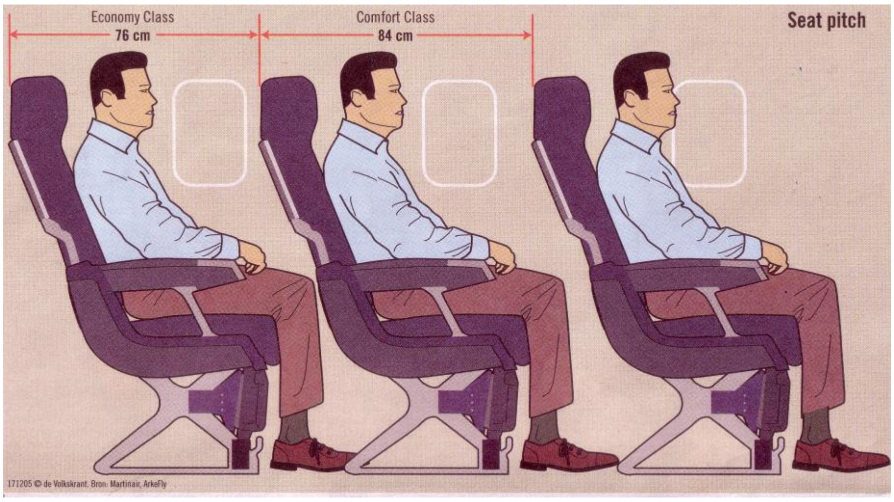


Figure 3-29: Economy class airplane seats (illustration: de Volkskrant)

In view of the activities one pursues in an airplane seat, this seat should have the properties both of an office chair and of an armchair. The basis is a stable posture that occurs with a backrest angle of 115º. In this posture one can eat or read. The back of the seat can be reclined a further 8º to 123º to watch television or to talk to one's neighbour. In this posture one can lower one's head ca. 20º backwards and rest it against the headrest. In the current airplane seats this is often not possible as the head support is too close so that one has to hold one's head against it actively. Obviously it is impossible to sleep in such a posture, however many cushions one is given.

In general, it can be said that the more critical the conditions of use – and having to sit for long periods is critical -, the more optimal the seating support should be. This also means that individual characteristics must be compensated for as well as they can be, especially when it comes to back support. The back support should afford space for the buttocks and the support of the back above the small of the back should ideally begin in the small of the back. A mechanism to adjust the height of the back support above the small of the back for each individual would greatly improve comfort as long as it were used properly, otherwise the remedy could be worse than the complaint.

Obviously the relation between the backrest angle and the seating angle should be correct so that frictional forces for the equilibrium of forces in the seat are avoided. The illustration in figure 3-29 does not seem to comply with this.

Finally: distribution of pressure and moisture and heat regulation should be optimal. That goes without saying.

3.3.3 Car seats

The one main characteristic of driving a vehicle is that one has one's eyes on the road all of the time. The gaze is permanently directed at the horizon. And one more or less automatically chooses a posture in which the head is in balance on the trunk and the neck and shoulder muscles are as relaxed as possible. This is in fact the posture that the references provide for the neurophysiological control system in the brain. There is hardly a more ideal basis for a posture and this is probably the most important reason why people can maintain such a posture for long periods at a time.
Car seats are adjustable so that one can find an individual, comfortable posture. The angle of the backrest can usually be adjusted gradually. The more luxurious the car, the more possibilities for individual adjustments it will have.
The posture one should be able to find in a car is the individually preferred posture. This posture has a functional backrest inclination (above the small of the back!) of about 123º when the back is individually supported. If that is not the case and the backrest is flat, then there will be great variation in the backrest inclinations chosen. Car seat manufacturers would do better to aim their efforts more at possibilities for individual back support than at the possibilities of adjusting the position of the backrest, angle($\varphi+\alpha$) that is going to be about 123º in any case.

Car designers should optimize the use of the steering wheel and the pedals and the accessibility of the dashboard from this basic principal and from this basic posture.
In cars that have not been designed from these basic points in this order, there is a great possibility that the necessary use of the wheel and the pedals will negatively influence the desired seating posture.

If one wishes to adjust the seat individually in any given car, one would be well advised to slide the seat right back as far as possible and then to adjust it comfortably as if one were going to watch television through the windscreen. Then one can consider the consequences for using the wheel and the pedals by sliding the seat forward again.

Figure 3-30: The individually preferred posture with the head in balance on the trunk as seating posture in a vehicle with a functional backrest angle: angle($\varphi+\alpha$) of ca. 123º.

The seating surface of a car seat is usually quite inflexible. This gives the pelvis a good seating stability which means that the pelvis then forms a good stable basis for the spinal column. The seating surface and backrest are contoured in cross section and give lateral support to the thighs and trunk.

Obviously, good moisture and heat regulation will contribute to comfort on long journeys.

3.4 Summary and conclusions

Analysis of sitting behaviour shows that people always try to relax as soon as the opportunity arises. Relaxation occurs in a stable posture which requires little muscle energy to maintain. The human body is able to create a stable posture that demands little muscle energy in the lower back. One arches ones back in kyphosis and 'hangs' in the extreme positions of the lumbar vertebrae that are held in connection by ligaments. This sort of stability is undesirable due to the severe, one-sided stress on the intervertebral discs and the severe stress on the ligaments. This sort of stability is called anatomically unsound stability.
Biomechanically seen, stability occurs in a posture in which the back is supported in such a way that the collective centre of mass of the trunk, head and arms is found on or above the lumbar section of the spinal column. This stability is shown to begin when the position of the trunk in space is 115º, defined as angle($\varphi+\alpha$). As this angle increases, so the stability increases. This angle is not different for each individual but is more or less the same for everybody. This stability is anatomically sound stability because the loads act on the spinal column in the correct way. The best taxation of the spinal column is achieved when the back is individually supported in such a way that the spinal column can follow its own natural curve.

Chairs and other furniture should be designed in such a way that activities that are carried out in a sitting position are catered for. It is difficult to think of any activity that demands a permanently active posture. During most activities an active posture is alternated with a relaxed, stable posture. 'Active' chairs, such as the majority of stacking chairs, dining room chairs, work(place) chairs and desk chairs should therefore provide a backrest with which anatomically sound stability can be realised. Furthermore, an active posture for an 'active' activity requires an almost horizontal seat: angle φ should be at most 3º. This angle is too small to prevent frictional forces in the seating surface in a relaxed stable posture. This chair concept should then be seen as a necessary compromise. Experiencing frictional forces in the seating surface is, however, not very high in the hierarchy of comfort perception. The feeling that one is about to slide out of one's seat is immediately perceived as irritating. These chairs should therefore – as an exception – have a seat upholstered with a fairly rough material.
Seats that are to be used for long periods at a time should really have an individually adjustable seating height.

Seats and furniture that are designed for activities where the direction of gaze is usually horizontal, such as for discussions, watching television, driving a vehicle and the like should be based on the characteristics of the individually preferred posture. This posture is determined by the position of the head in balance on the trunk. This is perceived as extremely comfortable because the neck muscles need exert the least effort in this posture. Contrary to what one would expect, the individually preferred posture proves to be a lot less than individual. The individually preferred posture is shown to have an average position of the trunk in space of about 123º. So the functional backrest angle: angle(φ+α) is ca.123º. For a proper equilibrium of forces without frictional forces in the seat, the seat angle, angle φ is then 18º and the sitting angle, angle α is 105º. Armchairs and sofas, but also car seats and seats in airplanes should comply with these basic points. The back support should be designed such that the back can adopt its own natural curve. If one has to use the seat for more extended periods then it is desirable to have a back support that can be individually adjusted in height with regards to the deepest point of the small of the back.

In the realisation of a sitting posture, the properties of the seat cushion and the back support play an important role. The sitting posture is after all defined by the situation under load. Cushions can as it were provide the fine tuning of the posture. Depending on their construction, cushions dent in a certain manner under the influence of loads. The primary function of the denting of cushions is to provide a good distribution of pressure. This is the distribution of the load over the surface of the buttocks or the back carrying the load. The greater the surface bearing the load, the lower the - average - pressure will be. With foam cushions, the shape of the supporting construction plays an important role in the distribution of pressure. The more the shape resembles the buttocks, the better the distribution of pressure. Obviously, the shape of the support construction is even more important in the case of thinly upholstered chairs.
Apart from distribution of pressure, cushions also provide moisture and heat regulation. Inefficient moisture and heat regulation is most uncomfortable for longer periods of time.

4.0 Sitting and sitting behaviour in a wheelchair

In previous chapters, human sitting behaviour was observed, analysed and explained and conclusions were drawn with respect to the required properties of various types of furniture. Sitting behaviour proves to be easily explicable when neurophysiological, physiological and biomechanical aspects are taken into consideration. One important conclusion is that people's specific sitting postures have much more in common with each other than one would initially expect.
The posture that gives a person stability, is shown to start by a functional backrest inclination, angle($\varphi+\alpha$) of 115º. This angle can be simply explained in biomechanical principles and is applicable for everybody.
The individually preferred posture also proves to be somewhat less than individual, at least, when the back is individually supported. In this posture, the head is in balance on the trunk and the gaze directed at the horizon. This posture gives optimal relative tension in the muscles in the neck and shoulders, resulting in a feeling of relaxation: the position of the trunk in space is about 123º.
With a combination of biomechanical and (neuro)physiological analyses, one can easily understand this specific posture.
On the basis of these statements, consequences were drawn with respect to the design and use of various types of chairs during different activities and in different situations. Suggestions were also made as to how sitting behaviour can be influenced in a positive way by optimisation of the seating support and of the work situation. The height of the screen of a computer was, for example, described as having a great influence on sitting behaviour.

This chapter is about people who depend on wheelchairs for their mobility and who must necessarily carry out all their activities while sitting in a wheelchair. In essence, a wheelchair is a wheeled chair, a chair with wheels. And indeed, that is exactly what the first wheelchairs looked like.

Figure 4-1: Wheeled chair . Bron: Stichting Humanitas Rotterdam

How does moving round by means of a wheelchair influence sitting posture? Which posture should a sitting posture in a wheelchair preferably resemble: the posture in a dining room chair, an office chair, a desk chair, a car seat or an armchair? Or should it resemble none of these as sitting in a wheelchair is something very specific and people have very special reasons to make use of this facility?
All very interesting questions that necessitate starting by considering the specific characteristics of wheelchair users and the extent to which they differ from people who are not wheelchair users.

4.1 Analysis of wheelchair users

The reason that people have to use a wheelchair is, in about 95% of cases, due to illness, old age or an accident. In about 5% of cases it is due to a congenital defect. This is an important observation. It means that 95% of wheelchair users once belonged to the group of people whose sitting behaviour has been extensively described and explained in the previous chapters. They have all gone through normal motory development and anthropometrically they belong to that part of the population categorized as 'normal'. The biomechanical model that has been used to explain some parts of sitting behaviour can be used for this group and there is no reason to suppose that biomechanical explanations using this model should not be applicable for this group. This means that stability for the trunk occurs and can be realised in an anatomically sound manner just as has already been described. This stability begins with a functional backrest inclination, angle($\varphi+\alpha$) of 115º if the definitions for sitting posture we have developed here are adhered to.

The question is, how much is the individually preferred posture with the head in balance on the trunk influenced by loss of function and how should this be handled. The explanation of the individually preferred posture makes use of biomechanical, (neuro)physiological considerations that mainly concern the head and neck region. In the individually preferred posture, passive stretching of the neck and shoulder muscles result in a compensating moment so that the head can stay in balance on the trunk with very little muscle exertion. This mechanism is confined to this region of the body and is not affected by loss of function in other parts of the body.
The position of the head in balance on the trunk is the neurophysiological reference for the control system in the brain. The body is also directed by this control system in the sitting posture: the better the input, the better the reference and the better the control. As the control system is a self learning and self maintaining system, offering a 'sound' sitting posture provides an important input for the control system to learn from. Therefore, offering and being able to realise an individually preferred posture independently is a precondition for maintaining the quality of the control system, especially when loss of function hampers this process.

This shows that all of the explanations developed from the analysis of normal sitting behaviour are equally valid for wheelchair users with loss of function due to an accident, illness or old age. There is cause to be even more meticulous in their case than with normal sitting behaviour as it is more critical due to the enforced need to function sitting down and the causes for this.

Then there is still the group of wheelchair users with a congenital condition. This group may be going through or may already have experienced an unusual bodily development which means that the general *results* for a stable posture and for the individually preferred posture are not applicable. The approach and the considerations at the basis of these results are, nonetheless, definitely applicable. The posture can be considered and analysed mutatis mutandis on the basis of a model in the same way as previously described.
Here, in the same way, in the realisation of stability, a pivot point in the lower back can be pinpointed in a model as the point in relation to which stability will occur. And here, a posture can also be determined in which the head is in balance on the trunk and that serves as a reference for the control system.
It is especially important to provide the best possible input for an unequivocal reference when the control system cannot operate 100% accurately due to loss of bodily function. This can be achieved by offering the best possible sitting posture for it to learn from.

Wheelchair users can be further categorised on the basis of their incapacity. A practical and very relevant classification is coupled to the extent of their ability to propel themselves independently and actively using their arms. If this is not possible then they are dependent on a power driven wheelchair or on the help of others.

The cause of the incapacity can be a problem with the functioning of the muscles or joints. Insight into the nature of the problem also gives insight into the capabilities that a person still has.
Functional impairment of the muscles can be described using three characteristics that are seen in various medical conditions and can occur in various combinations:
• loss or reduction of strength,
• loss or reduction of stamina,
• loss or reduction of coordination.

It is important to ascertain whether the condition is symmetric or asymmetric (that is more or only on one side).
Symmetric, two-sided conditions can occur locally, for example as a result of a spinal cord lesion.

Problems with brain function arising in later life, for example, as the result of a stroke, often manifest more or only on one side.

Problems with joint function can be described by
• reduction of mobility and/or stability,
• joint anomalies.
The limitation of movement can be caused by either a 'mechanical' restriction or by pain experienced during movement.

Contractures of muscles, tendons, tissue or skin around a joint are often the result of extended immobilisation. This contracture causes anomalies of the joint that can be reduced or eliminated by therapy and/or operatively. Certain joint conditions can necessitate operative fixation of that joint, a so-called arthrodesis. In this way an effort is made to maintain some functionality of the part of the body to which the joint belongs. In the case of hip and knee joints these procedures are usually only carried out on one side.

Special forms of anomaly in the spinal column are extreme lordosis, scoliosis and extreme kyphosis.

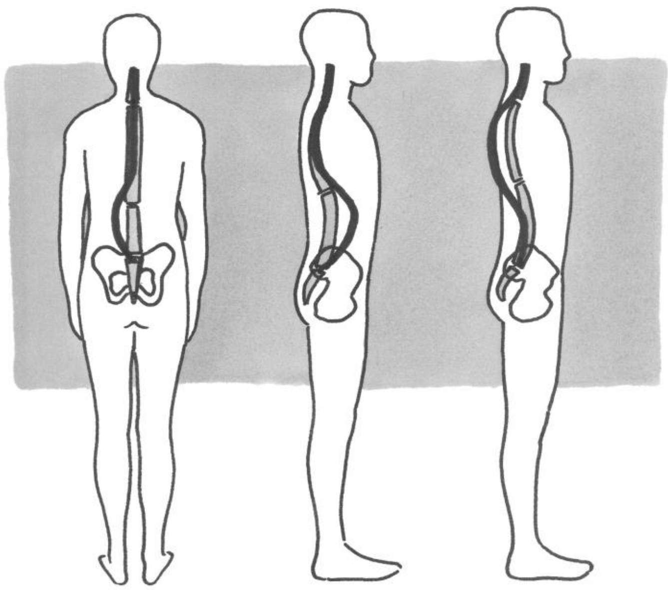


Figure 4-2: Various pathological shapes of the back: c. scoliosis, lumbar hyperlordosis and thoracic hyperkyphosis

4.1.1 The basic sitting posture

In the analysis of normal sitting behaviour it was shown that during activities that require an active sitting posture, people always have the tendency to adopt a more relaxed posture as soon as the activity allows: an active posture is relieved by a semi-active, stable posture that demands little energy and offers relaxation. Dining room chairs and office chairs were analyzed with this observation in mind. When an activity does not require any hand-eye coordination and the direction of gaze is mainly horizontal, such as when watching television or carrying on a conversation, people intuitively try to relax their neck and shoulder muscles. In a good armchair or sofa, this is possible. The trunk is supported in such a way that the head is in balance on the trunk and little energy is needed to keep the head in this position. This is the posture that is also sought when driving a vehicle

If we translate this normal sitting behaviour to a (wheel)chair in which one is forced to sit all day long and from which one has to carry out all manner of activities, then the conclusion is that the wheelchair should ideally offer the same sitting functionality as a dinning room chair, an office chair, a car seat, an armchair and a seat in an airplane.

If, however, due to diverse reasons, a wheelchair design affords only one sitting posture from which, during the course of the day, a wide variety of activities have to be carried out, then it is clear that the sitting posture of that wheelchair must provide stability and preferably an anatomically sound stability. This means that the back should be supported in its natural physiological curve and that the defined angle of inclination of the backrest, angle($\varphi+\alpha$) should be greater than 115º.

Figure 4-3: In search of stability for the trunk in a so-called active wheelchair by steadying the trunk from behind by leaning an arm on the tubular frame of the backrest.

A good example of this sort of sitting posture is the design for the auditorium seat by Wotzka that was presented earlier as basis for the general office chair. Whereas the seating angle had to be adjusted as a compromise in that case, in this application it is neither necessary nor desired

The *adjusted* profile of the auditorium chair by Wotzka will now be promoted to a basis for the wheelchair sitting posture. Refer to figure 4-4 and imagine the diagram with wheels. It should be possible to reposition the backrest of the wheelchair in relation to the lowest point of the small of the back in able to provide a really individual support. The backrest in this profile has been lowered in relation to the original profile. The grid is 10 x 10 cm.

The backrest has an angle($\varphi+\alpha$) of at least 115º and unlike the dining room chair, the seat here has an angle φ of 12º so as to prevent frictional forces in the seating surface and the long-term effects they would cause. In this posture the head is in an *active* position on the trunk.

This semi-active, stable sitting posture can be seen as the *minimum basic sitting posture* for wheelchair users, based purely on the analysis of *normal* sitting behaviour and *normal* biomechanical function. Minimum in this context means that more rather than less stability should be offered.

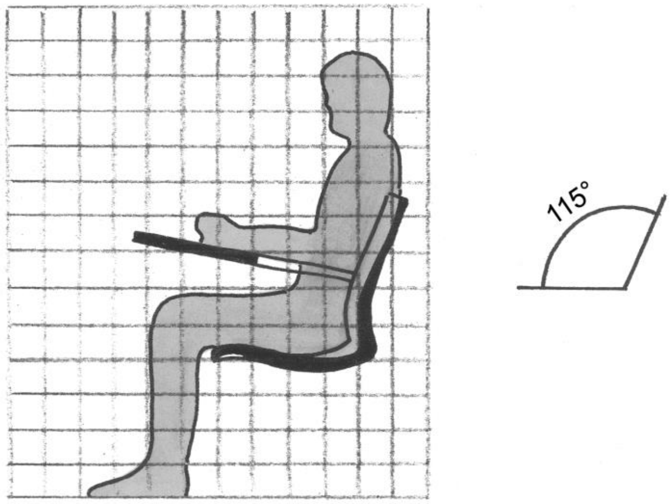


Figure 4-4: The anatomically sound, stable, basic sitting posture for a wheelchair: angle(φ+α) = 115º, angle φ = 12º after Wotzka in a grid of 10 x 10 cm.

This semi-active, stable sitting posture can be seen as the *minimum basic sitting posture* for wheelchair users, based purely on the analysis of *normal* sitting behaviour and *normal* biomechanical function. Minimum in this context means that more rather than less stability should be offered.
This semi-active sitting posture is a *compromise* between a transfer posture, an active posture and an individually preferred posture when only one sitting posture is afforded by the wheelchair.

The basic sitting posture for a wheelchair is, therefore, actually *irrespective* of the physical ability or inability of the wheelchair user. If there is an inability to actively stabilise the trunk, then this basic posture will give the stability that cannot be actively realised in any other way because of the inability. It is also possible to increase the backrest inclination a little to, for example, 117º so that the stability is less critical. After all, on average, stability *begins* at 115º.

In the case of abnormal curvature such as scoliosis or kyphoscoliosis, a stable sitting posture is of the utmost importance. After all, the less these abnormal curvatures sustain loads the better. If the posture is more stable there will be fewer loads on the spinal column. A stable posture will never be achieved with an angle(φ+α) of less than 115º in this sort of case.

4.1.2 Dynamic sitting behaviour

Normal sitting behaviour is dynamic. It stems from continual change of posture to accommodate activities and the need for stability and relaxation. At the same time, it can be stimulated by sensations that are intended to prevent long-term local overloading. The body, and in particular the (muscle)tissue, is after all not equipped for - active or passive - static loads.
Enforced, continual sitting every day brings with it the threat of too high a static load on the buttocks for too long a period. A wheelchair user will profit greatly from

dynamic sitting behaviour. It will prevent decubitus, one of the greatest risks accompanying long periods of sitting.

Dynamic sitting behaviour is encouraged if the wheelchair offers the possibility of adapting one's sitting posture to what one is doing. From the semi-active basic posture one could change to the individually preferred posture for a conversation or to watch television. Then one could enjoy a meal back in the semi-active basic posture. One could have a snooze in the individually preferred posture using a headrest to support one's head or in a posture that leans back a few more degrees than usual.
From the basic posture, the seating angle, angle φ can be optimised for making a transfer by reducing it to 0º.
One practical, technical solution for this change of posture would be to tilt the entire posture backwards or forwards. The functional zone from the basic posture is approximately 8º backwards from 115º to 123º. As this is a relatively small angle, the – theoretically necessary – adjustment of the seating angle can be omitted for practical reasons. There are construction principles for this tilting where the centre of mass of the user stays in the same place which is of importance for the stability of the wheelchair.

Figure 4-5: From the basic posture to the individually preferred posture: angle($\varphi+\alpha$) from 116 º to 123º.

When tilting forwards through approximately 12º to optimise the transfer, the position of the backrest is not relevant. One is, after all, preparing to make a transfer.

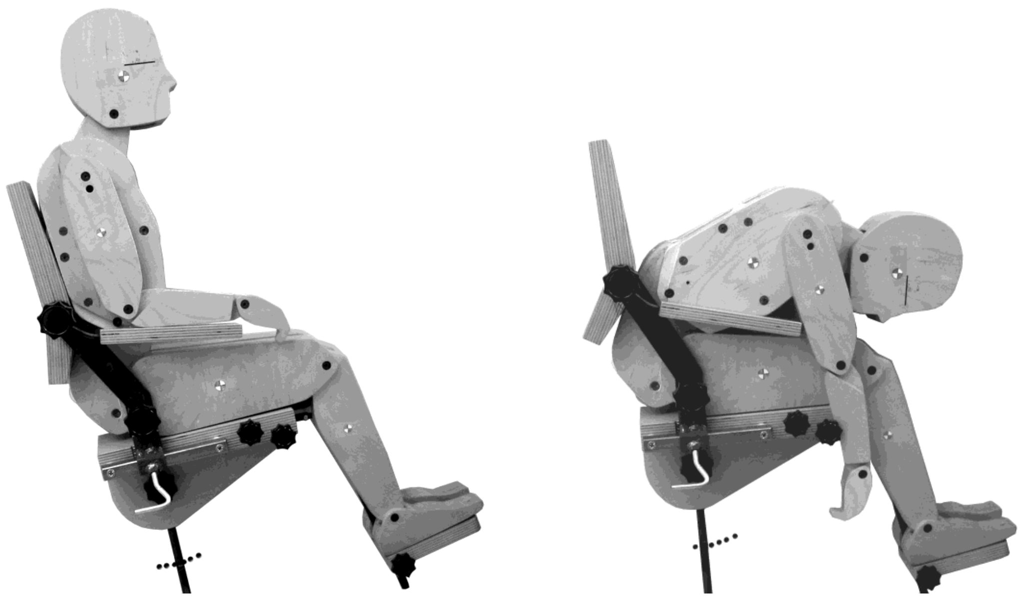


Figure 4-6: From the stable basic posture to an unstable transfer posture: angle φ from 12º to 0º.

The technical realisation of a posture adjustment in a wheelchair does, of course, make great demands on the construction and makes the wheelchair rather more expensive. A distinction can be made between electrical adjustment that can be operated by the user and a form of adjustment that can only be operated by a carer. The latter solution is, of course, only acceptable for wheelchair users who can no longer make adjustments themselves due to reduced cognisance.

4.1.3 Supporting the head

The biomechanical properties of the position of the head are, in a sense, special. The centre of mass is approximately 20º in front of the pivot point, the atlas. The position of the head 'in balance on the trunk' occurs through kyphosing of the upper part of the trunk. The resulting passive stretching of the muscles and ligaments cause a counter moment which leaves the head in 'balance'. This happens when the functional backrest inclination, angle(φ+α) is approximately 123º.
Neurophysiologically, this position provides the reference for the control system in the brain.

Supporting the head from behind in this position makes very little sense as from a biomechanical point of view this has, and indeed can have, no effect.

If the loss of function is such that the neck and shoulder muscles have reduced tonus/power and there are signs of a failing balance mechanism for the head, then the head must be supported in such a way that a good balance position can be maintained which may not hamper the optimal proprioception in the head and neck region. Obviously it is of the utmost importance that a sitting posture is afforded with an individual support for the back and that the best backrest angle is sought so that the head can balance on the trunk in a natural manner. From this posture one can try to 'catch' the head by the lower jaw should it tend to fall sideways or forwards. In figure 4-7 an example is given of the way in which this can best be effectuated.

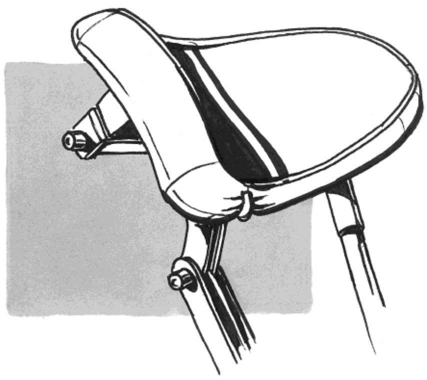


Figure 4-7: Catching the head under the chin in the case of limited head balance

The head is in a stable position to rest when it is tilted 20º backwards and resting on a head support. Now the gaze is directed at the ceiling and one is no longer participating in social interchange. The head support must be positioned far enough behind the head to facilitate this.

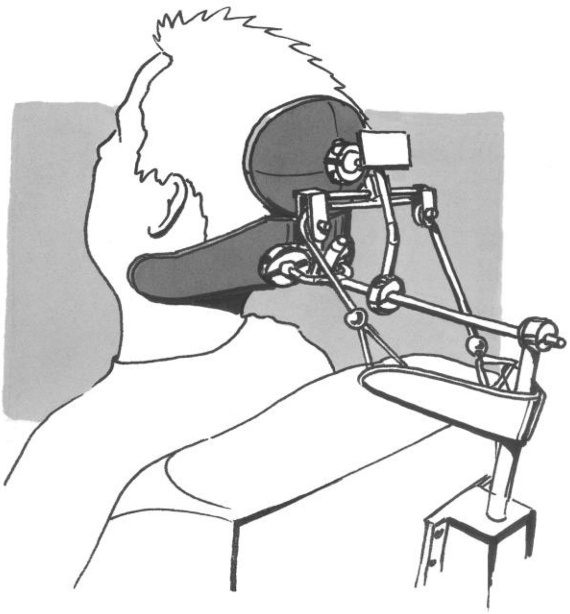


Figure 4-8: Head resting in a stable position on a headrest. The relaxed gaze is directed upwards.

An extraordinary situation occurs when a backrest is inclined farther backwards than is necessary to keep the 'head in balance on the trunk'. Anyone can experience this sort of situation where the head has to be held up by muscle power, for example, when watching television.
As this is very tiring, most people have the tendency to support their head with both arms as can be seen in figure 4-9.

Figure 4-9: Supporting the head in a posture with functional backrest angle, angle(φ+α) > 123º to compensate for extra muscle exertion in the neck and shoulders.

A headrest, that then obviously must be positioned correctly, could take over the function of the arms. Whether this posture is comfortable after a period of time is highly questionable. This matter has been raised to demonstrate what happens when a carer places someone in a posture that inclines too far backwards. In nursing homes, many elderly people are confined to a wheelchair that can only be adjusted backwards into a comfortable posture by a carer. This must therefore be done very meticulously. Too far backwards and the result is as above and that is anything but comfortable. This sort of chair should really be adjusted only once to suit one individual person, so that this mistake can no longer be made.

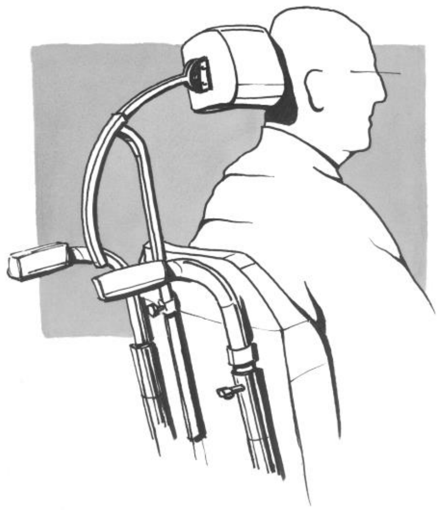


Figure 4-10: The position of this headrest is effective in preventing whiplash in the case of a car crash. However, in this position, it is not at all effective as a support for the head during an afternoon nap.

Finally, a function that can also be shared by the wheelchair headrest: that of the headrest on a car seat. Many wheelchair users cover great distances in wheelchair buses. The wheelchair is anchored to the floor of the bus and the whole thing functions as a car seat including a headrest that is effective should any vehicle drive into the back of the bus.

4.2 Preventive and curative aspects of the sitting posture

The primary objective of a sitting posture is functional. A posture is geared to what one intends to do. As well as this, a sitting posture and sitting behaviour can be used in a preventive or curative approach.

Sitting postures and sitting behaviour can be a positive stimulation to start up and maintain a learning process based on the sensorimotor reafference principle by means of offering 'examples of sound and desired postures'. Postures are registered by the senses and transmitted to the control system in the brain. Conversely, muscles are controlled on the basis of these known mobility patterns from the brain. An unequivocal (neurophysiological) reference is a precondition for this. This reference must also be continually confirmed and, as it were, reset.

This principle applies for normal sitting behaviour but is also applies pre-eminently for sitting behaviour in the case of wheelchair users because this phenomenon works both preventively and curatively.
The idea behind this is that the control system in the brain needs as much known and therefore identical input as possible in order to facilitate or to recondition known action-reaction patterns, or to prevent pathological patterns that arise from incorrect input.
It is of great importance that the muscles are also kept 'at the right length' by offering postures other than just a sitting posture in the course of each day. This is also important for maintaining properly functioning proprioception. Therapy using a standing aid proves to be efficacious here. See figure 4-11.

While maintaining a sitting posture, the pressure on the body from the reactive forces from the supporting elements is the dominant external factor that determines muscle tonus.

Figure 4-11: Therapy with a standing aid to keep the muscles at the right length and to stimulate proprioception.

This means that the magnitude and the direction of the external loads are extremely important. Equilibrium of forces in a sitting posture where there are no frictional forces is, therefore, in a neurophysiological sense, a necessity. Unsound postures with frictional forces are, after all, not recognised as such by the control system of wheelchair users with impaired sensibility. This can send the control system's programming awry. The same applies for internal loads. Supporting the back in its own natural curve is an absolute precondition for optimal internal loads. A sitting posture with the head in balance on the trunk can then provide an unimpaired, optimal reference and optimal input.

The conclusion of these considerations is that the mechanisms that are the basis of 'normal' sitting behaviour should also be stimulated in people who are forced to sit all day long due to physical impairments and limitations.
This generally implies that a wheelchair user should be able to adopt several sitting postures on their own and that sitting posture and seating support should offer the maximum amount of comfort. Comfort, after all, means simply that all external and internal loads have been optimised and are therefore hardly noticed.

4.2.1 Reduced coordination

If postures can no longer be maintained at will or cannot be adopted within a certain time or space, then we speak of reduced posture coordination.
The most common form of reduced coordination is spasticity.

Spasticity is a phenomenon that is characterised by abnormal reflex activity, excessive muscular tone (hypertonus) and an inability to move in a coordinated manner.
These characteristics occur in a certain relation to each other. The cause of spasticity lies within the Central Nervous System (CNS).

Certain postures or movements, externally induced (by a therapist), prove to have a direct influence on relieving spasticity. These are called Reflex Inhibitive Postures and Reflex Inhibitive Movements. These postures have such a 'positive' influence on the proprioceptive input from the muscles to the CNS that this results in the reduction of spasm.
Keypoints of control in the search for and programming of these postures and movements are body locations from which the posture reflex activity can be influenced therapeutically. The most important ones are:
• the head/neck region: the position of the head in space,
• the lumbar sacral transition region:
  the extent of lumbar lordosis – here, position of the pelvis: angle λ,
• the hip angle, angle α,
• the palms of the hands in relation to the flexion position of the wrists,
• the soles of the feet in relation to the flexion position of the ankles.

The basic posture for a Reflex Inhibitive Posture is in principle *the individually preferred posture,* because in this posture the input is optimal (read: is received in its most unimpaired form). In order to find this basic posture successfully for any individual, it is highly advisable to start from a posture with a backrest inclination, angle($\varphi+\alpha$) of 123º, a hip angle, angle α of 105º and an individual back support. This is because in this posture the head is in balance on the trunk and the gaze directed at the horizon, there is minimal internal stress and there is equilibrium of the reactive forces of the supports for the back and the buttocks without any friction.
It should be noted that wheelchair users with a congenital condition may not be able to produce any other values for an individually preferred posture due to an unusual motory development and possibly less than optimal sitting behaviour.

Starting from the general basic posture, the posture can be individually optimised.
The position of the head in balance on the trunk is the most important basic point with the precondition that the individual shape of the back should be perfectly supported as an important keypoint of control that inhibits the tonal reflex activity and normalises posture tonus.
One should observe the behaviour of the head while slowly altering the posture with a fixed angle α of between 103º and 105º. The individually preferred posture can easily be recognised with some practice.

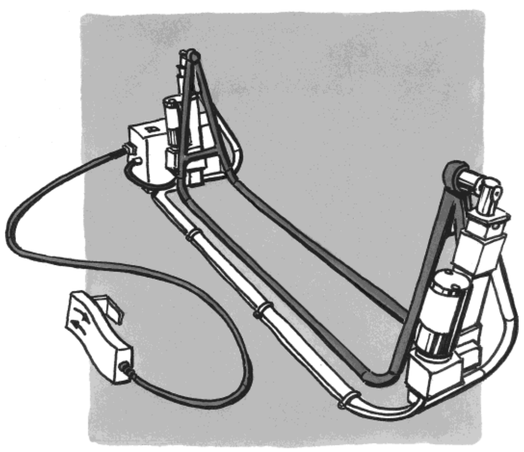


Figure 4-12: A simple instrument to influence angle(φ+α) during a fitting to find the individually preferred posture.

It is important here to emphasize once again that the position of the trunk in space is determined (and defined) by the angle that the section of the trunk *above* the lowest point of the small of the back makes with the horizontal. This part of the back should be considered as the basis for supporting the trunk in a stable posture. From this minimal but stable support, the individual curve of the back is sought by manipulating the position of the backrest in relation to the seat.

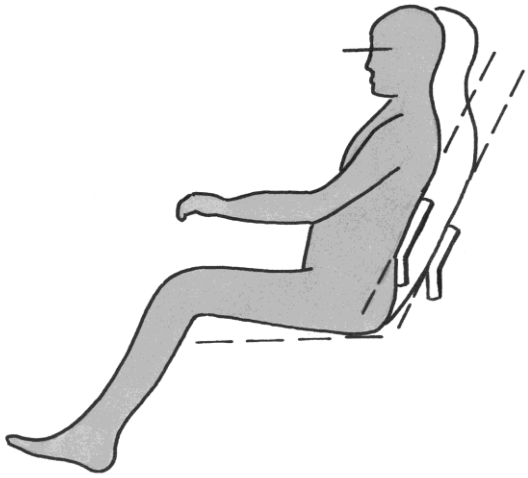


Figure 4-13: Influence of the position of the backrest in relation to the seat on the curve of the back.

This is followed by supporting the sacral and lastly the thoracic regions of the back. This completes the individual support for the back and now the individually preferred posture can be sought by slowly varying the posture and observing the reaction to the position of the head.

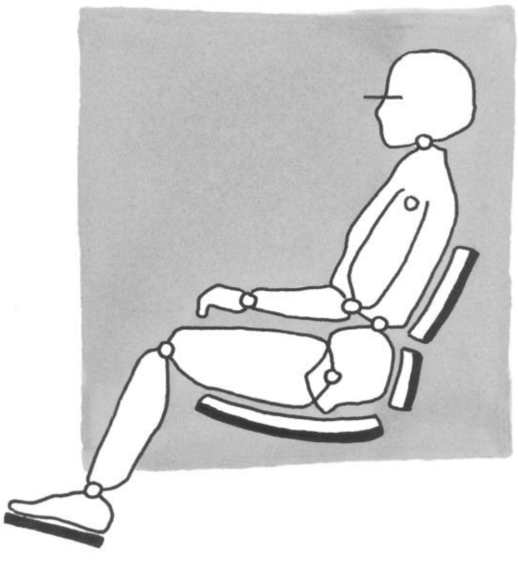


Figure 4-14: Principle for a back support with the lumbar-thoracic transition area (LT) as basis for the support and the posture. The sacral area (S) of the support facilitates the individual curve of the back.

The support principle described here is in fact a practical translation of the procedure followed using the fitting chair to determine the individually preferred posture. This procedure is described in paragraph 2.4.

When the back has been given proper individual support, the degree of backrest inclination, angle($\varphi+\alpha$) and the size of the hip angle, angle α are the next parameters for the optimisation of the individually preferred posture.

Obviously, the position of the pelvis and along with that the shape of the back are also influenced by the way a person sits down or is set in a given wheelchair. The position of the tuberosities on the seat cushion will, after all, determine the distance to the backrest and the magnitude of the backward tilt of the pelvis and therefore the shape of the lumbar spinal column, an important 'keypoint of control'.

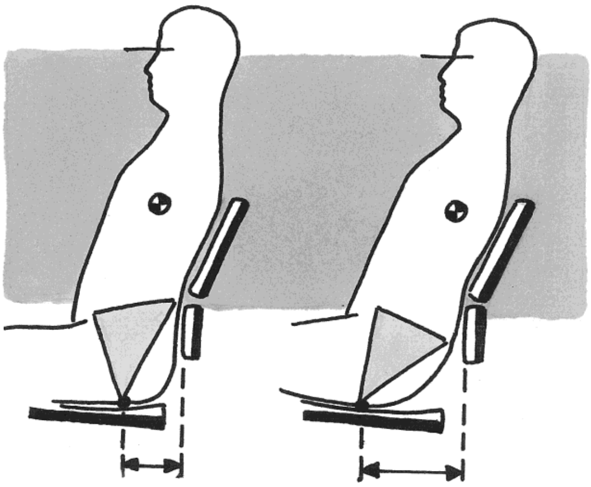


Figure 4-15: Influence of the position of the tuberosities on the seat cushion on the position of the pelvis and the shape of the back.

The following points should be noted in the further fine-tuning and optimisation of the reflex inhibiting posture.

Certain continual pressure sensations on the skin and/or the experience of stimulations on reflex zones in the skin usually have a predictable influence on muscle tone:
• A permanent low pressure usually gives reduction of tonus;
rubbing nearly always gives an increase in tonus. This emphasizes the importance of establishing a good equilibrium of forces in the sitting posture through a good relation between angle φ and angle α and the importance of a good distribution of pressure in the seat and backrest.
• Stimulation of the area of skin located at Th. 4-8 gives an increase of tonus in the muscular system of the back and the upper extremities and reduction of tonus in the lower extremities. This positive stimulus can be built into the backrest profile.
• Stimulation of the area of skin located on the adductors of the lower extremities usually gives an increase in the tonus of the lower extremities and a reduction of the extension-activity of the musculature of the back.
The pressure distributing properties of the seat cushion and the shape of the support can play a role here. The thighs should be turned slightly outwards by the shape of the cushion (abduction/exorotation).
• Pressure and permanent stimulation of the palms of the hands nearly always give a reduced abnormal extension reaction in the upper extremities. *Sudden* stimulation of the palms of the hands usually gives an increase in the flexion of the upper extremities.

• Permanent pressure on the soles of the feet gives a reduction of the extension tonus of the lower extremities (crossed reflexes may occur here).
A sudden stimulation of the soles of the feet gives an increase of extension tonus in the lower extremities.
• Lying on one’s back with the head in a more or less neutral position reduces extreme flexion activity.

The author’s own research has shown that from a real, individually adjusted reflex inhibiting posture, a certain margin for extra spontaneous stimulation arises: this does not necessarily result in an increase of spasticity.

Wheelchair users with spasticity must experience the feeling of normal muscle tonus and movement. As, on their own, they do not know how they should move in a proper way, they should be supervised in this. Wheelchairs with programmable movement patterns can be helpful here by causing the movements to 'happen' in the wheelchair and can 'imprint' them by repetition of these 'positive', sensory stimuli. This methodology follows the so-called *reinforcement* principles.

Reduction of spasticity makes it possible to achieve a starting point for potential formation of selective movements.
For each person, several reflex inhibitive postures should be found, that can then be initiated by the person themselves or by the carer. In this way the basis is formed for Reflex Inhibitive Movements.These movements are essential as spasticity increases through lack of movement.
Finally, a few remarks about approaching people with spasticity in case treatment. Emotions, as well as associative reactions can influence muscle tonus. Fast changes of environment or situation can result in an increase of muscle tonus due to a shock reaction.
For case treatment this means that someone with spasticity should be approached and addressed with the utmost care and calmness.

4.2.2 One-sided limitation of leg and arm function

Paralysis of one side of the body, hemiplegia, usually results from a stroke (CVA), that has caused damage to structures within the left or right half of the brain.
Part of the initial loss or reduction of muscle function can often be regained or compensated for by training.
The basis for this training is stimulation of the affected side through *symmetrical movement and changes of posture.* In this way a learning process based on the sensorimotor reafference principle is started. Postures are registered by the senses and transmitted to the brain. Conversely, muscles are controlled from the brain on the basis of known patterns of movement. Patterns of movement lost due to brain damage can in this way be relearnt as other brain tissue takes over the lost functions.
One-sided failure leads to an imbalance in the body, both in a morphological sense, the asymmetry of body parts, as in a physiological sense, in maintaining body postures. Activities such as 'propulsion' and the 'maintenance of sitting postures' should always be based on as complete a symmetry as possible of the left and right sides in relation to each other.

Asymmetrical propulsion using physical strength, the so-called hemiplegic pattern is, from this point of view, not to be desired and therefore not advisable. It is, after all, not a symmetrical activity and it does not carry any learning effect for the affected side. Furthermore, it results almost by definition in a non-symmetrical sitting posture in which undesirable friction forces are needed to reach equilibrium of forces.
The most appropriate propulsion for this group of wheelchair users is at least electrically driven propulsion with central steering using both hands. In view of the usual levels of *neglect* it is advisable to limit the maximum speed to ($V< 2$ km/hr). It is almost inevitable that there will be a collision with a doorpost at some point, but this happens with the hemiplegic pattern as well. This is the reason for the low speed.

The sitting posture should be as symmetrical as can be in a stable posture, if possible an individually preferred posture, with an angle($\varphi+\alpha$) of approximately 123º but never less than 115º. Extra side supports at the height of the lowest point of the waist triangle are advisable.

Special attention should be given to supporting the arms and legs: prevent exorotation of the affected leg and plantair flexion of the foot.
The affected arm should be supported at the correct height in such a way that the arm cannot fall off of the armrest.
Usually this will entail widening the armrest. It is also important to keep the affected arm and leg within the field of vision as much as possible because spatial perception is often defective as a result of the brain damage.
Fixed armrests facing inwards allow symmetrical manipulations whilst the feet remain in view. In figure 4-16 an example of this principle is presented.

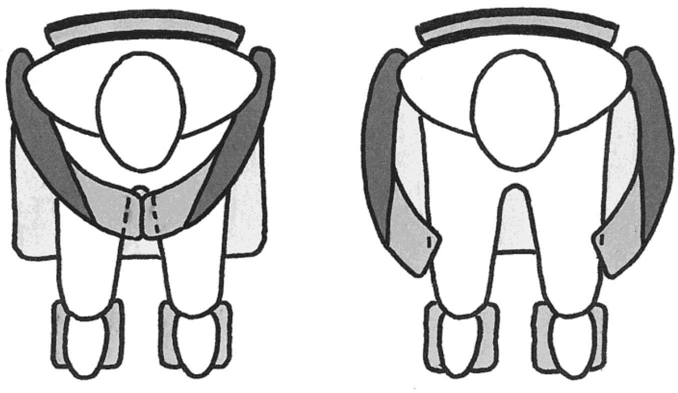


Figure 4-16: Principle of inward facing armrests with transparant middle section allowing view of the feet for symmetrical manipulations in hemiplegia.

The solution presented here is an alternative for the wheelchair work top. It has certain cosmetic advantages and also advantages for activities of daily life (adl).

4.2.3 Anomalies

Long-term use of a wheelchair can easily lead to anomalies in the hip and knee joints if preventive therapy is not or cannot be successful due to the medical condition.
In these cases, the sitting posture should be arranged in such a way that these anomalies are optimally allowed for, especially if these anomalies are accompanied by pain. Badly adjusted support surfaces, after all, will give too little support or too great a load on the locked joint. In practice, it will not be too difficult to adjust the supporting elements correctly in a fitting session. The emphasis during the fitting session should lie on the ability to actually reproduce this posture after a transfer, either alone or with assistance. This is generally an enormous problem for wheelchair users, especially when there are joint anomalies involved.
'Sitting down' should be an integral part of advice and training. The possibilities of tilt mechanisms can be used to optimise sitting down in a wheelchair. With an angle φ of, for example, 20°, gravity will help to get the pelvis to the back of the seat. Of course, the seat cover must then be made of a smooth material.

With complete support of the body using supporting elements, the equilibrium of forces is independent of the mobility of the joints. This means, in practice, that anatomically sound, stable sitting postures can be created in which there are no frictional forces in the equilibrium of forces.

One-sided anomaly
Where there is a one-sided contracture of the hip, this is usually due to fixation of the hip joint (arthrodesis) at an angle of 135°. The symmetry in relation to the sagittal plane is thus lost and support using a seat cushion becomes problematic, mainly because on the side of the arthrodesis, the ischial tuberosity on which half of the seating weight should be supported has, as it were, disappeared 'into' the thigh. The support surface of this tuberosity can, therefore, not be anything other than very small. If this support surface is too deep, then the person will have a tendency to correct this by rotating the pelvis in the transverse plane. This should be prevented. The support for the seat will give the most balanced distribution of forces if the angle φ for the arthrodesis free leg is slightly larger than it should be for the posture. Starting from the stable basic posture with a backrest inclination, angle(φ+α) of at least 115º, the arthrodesis free leg will have an angle φ of at least 15º.

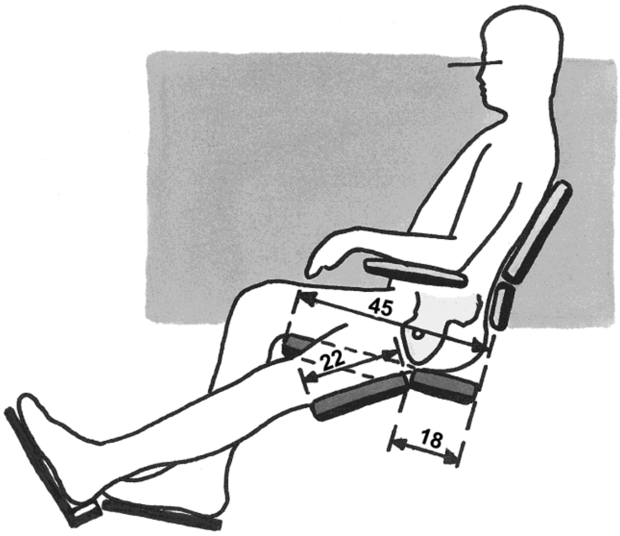


Figure 4-17: Posture and measurements of an arthrodesis seat.

The shape and mobility of the lumbar spinal column
A stable sitting posture does not depend on the shape of the lumbar spinal column. The position of the trunk in space is, after all, defined as the line of contact of that part of the trunk above the lowest part of the small of the back, around L3-L4.

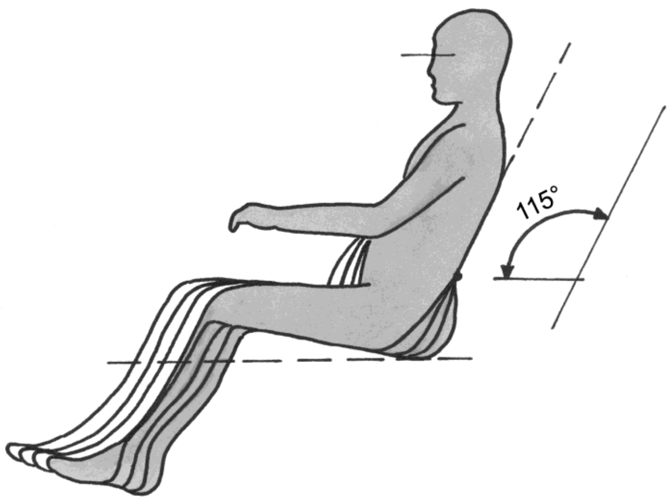


Figure 4-18: The definition of angle(φ+α) is independent of the shape of the back.

The position of the pelvis when one is standing or sitting determines the shape that the lumbar spine is 'forced' into, if the lumbar spinal column is mobile. Conversely, an immobile lumbar spinal column forces the pelvis into a certain position: a lumbar spine with a hyperlordosis or a nearly flat lordosis will position the pelvis in a forward, respectively backward tilt.
Extreme positions of the lumbar spine will be compensated for by the neck in order to obtain a good line of vision.

A fairly flat lordosis in the lumbar spine leads to a pronounced thoracic kyphosis and the position of the head will be compensated for by a more pronounced lordosis in the cervical spine.

The way in which the stability of the upper body is achieved is determined by the position of the centre of mass of the entire upper body, head, trunk and arms, in relation to a modelled lumbar pivot point. This centre of mass of the entire upper body is situated approximately at the height of the armpit when the arms are folded in the lap. Stability occurs with an angle($\varphi+\alpha$) of at least 115º.

In the case of a consciously or unconsciously chosen, immobile, often flat or kyphotic back it is possible to see a special form of 'stability'.
As the lumbar spine is immobile it cannot function as a pivot point for the stability of the upper body. In such a case the pivot point moves to the tuberosities. If the line of the effect of gravity runs behind the tuberosities, as is visualised in figure 4-19, then a non-active stability arises, but this goes along with a - large – moment of force Gb * a on the lumbar spine.

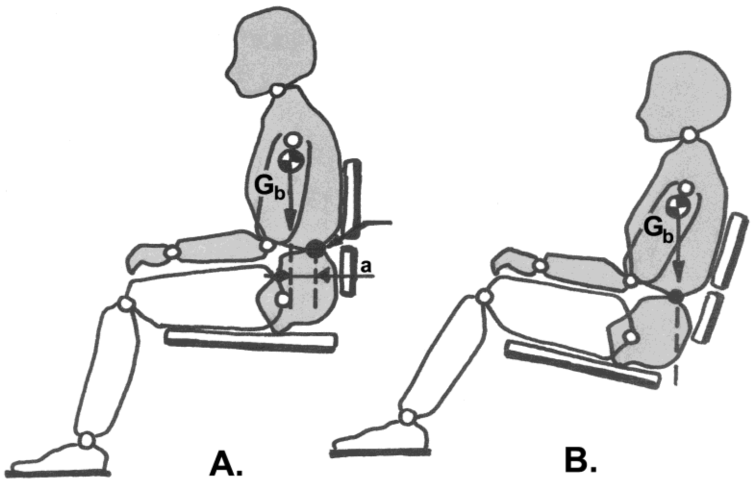


*Figure 4-19: A: Stability for the trunk with an immobile lumbar spine with the tuberosities as pivot point but with the introduction of a moment of force Gb * a on the lumbar spine. B: anatomically sound stability without kyphosing moment on the lumbar spine.*

In this posture, the ligaments of the lumbar spine will, if the period of time is long enough, be stretched under the influence of this moment, which will cause the kyphosis to progress and eventually the process will be irreversible.

Kyphosing of the lumbar region of the back also carries consequences for the position of the head in relation to the trunk. As the thoracic region of the trunk tends to hang forward due to the kyphosis, the head will have to be lifted higher by increasing the neck extension for the gaze to be directed at the horizon. This is a situation that can often be observed in the elderly.

A solution for this situation is found by tilting the sitting posture by increasing the angle(φ+α) to at least 115º and thereby creating a posture as it would be if the lumbar spine were mobile.

Scoliosis
The shape of the lumbar spinal column when seen from the front is usually straight. A lateral anomaly in this shape is called scoliosis.
A lateral curve in the lumbar spine is compensated for in the cervical region in connection with the horizontal line of vision. As a result the spine takes on an S-shape.

Comparison with earlier analyses clearly shows that the load situation of a spine with scoliosis is extremely unfavourable. The regions of the spine that lie outside of the vertical line are influenced by moments. This means that the load becomes greater as the distance from the vertical increases. These loads will especially affect the ligaments. Stretching these ligaments will entail an increase in the curve and therefore in the load.
In the case of a scoliosis, it is important to choose a sitting posture that is very stable: angle(φ+α) > 118º. In the frontal surface, a corrective or preventive three-point support is offered as is visualised in figure 4-20.

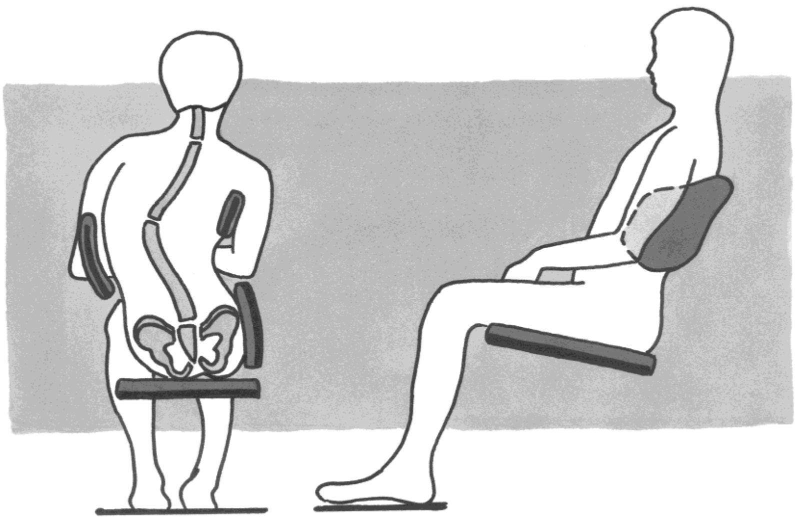


Figure 4-20: An effective three-point support for a scoliosis in a stable sitting posture with a backrest inclination, angle(φ+α) > 118º.

It is clear that this three-point support becomes more effective as angle(φ+α) increases as then the upper body will be pulled further into the backrest by gravity. Furthermore, a greater angle(φ+α) will provide more favourable loads, not only because with the increase of this angle the load along the spinal column will decrease causing the moment in the spinal column in the frontal surface to decrease, but also because in the sagittal plane the 'moment'-load on the lumbar spinal column will decrease.

4.3 Children and wheelchairs

Approximately five percent of adult wheelchair users are in a wheelchair because of congenital conditions. Most of them will have grown up with a wheelchair.

Without going into details on the consequences of the various congenital conditions, the relevant question here is, to what extent are the principles for sitting and sitting behaviour developed in this book applicable for children. And if they differ, in what way do they differ?
If an adult needs to start using a wheelchair because of illness or old age, they will have gone through a normal motory and psychological development. The body will be full grown before the need for the wheelchair arises.
A child still has to travel down this long road. It wants to discover the world, is inquisitive, eager to learn and active. Having to use a wheelchair does not diminish these characteristics. A child in a wheelchair will, in principle, pass through all the same phases of development as any other child. But the phases can run differently and the results can be different depending on the condition and the possibilities offered or the situation the child finds itself in.
So, sitting in a wheelchair will be a part of the motory and psychological development of the child and will obviously have a great influence on this. In which way can the wheelchair and sitting behaviour provide a positive contribution to this development?

In the first place, the wheelchair provides a child the possibility of discovering ‘the world’. The child should be able to move around *independently* at the earliest possible moment and not be dependent on carers for movement. It is already dependent enough. The design and colour of the wheelchair should be in line with the child’s perception of their environment so that it will be readily accepted.
There are many good examples of these concepts available. In figure 4.21 an electrically driven wheelchair that can be adjusted in height is shown.

Figure 4-21: The Squirrel: a children’s electrically driven wheelchair with vertical and tilt adjustment.

The starting point for the wheelchair concept should be that the wheelchair stimulates the child’s physical and motory development in a manner as close to normal as possible by affording the correct preconditions and situations in combination with a desired sitting behaviour that can be learnt. A child should be taught to use the possibilities *consciously* and in the correct manner. This can be done by associating specific activities with specific postures as is done with adults.

The (neuro)physiological mechanisms that have been described for adults are also applicable to children. Children, however, are in a learning phase which makes it even more important to afford sound postures and movements than in the case of adults. There it is mostly a case of 'maintaining' systems that have already been developed.

The result of the learning process may be different due to the medical condition. This partly depends on the possibilities and situations afforded. As a child is developing, the possibilities afforded and their uses are even more critical than in adult wheelchair users. They should therefore be applied much more meticulously because otherwise the wrong sort of development could be triggered.

If, due to loss of function, the control system in the brain does not work 100%, it is important to provide the best possible input by offering a posture that will result in an unequivocal reference. So a child also needs a stable, individually preferred posture with its head in balance on its trunk. And again, for children it is also applicable that an individual support for the back is a necessary precondition in order to obtain the optimal conditions for input. The functional backrest inclination of the individually preferred posture may give a different value than the average angle for adults as a result of the unusual motory and physical development but this does not detract from the principle.

Biomechanical principles for adults are also relevant and applicable for children. An anatomically sound stability will occur in the same manner as with adults and – very probably – with the same functional backrest inclination.

As a child is so active and also writes and draws a lot, a work top is often fitted to the wheelchair. Using this work top will usually result in the child adopting a – stable – posture by supporting its trunk with its arms. In this posture the pelvis will be tilted backwards and the lumbar spinal column will be suspended in its own ligaments. Earlier we mentioned that this is an anatomically unsound stability. With a developing child, this posture is more or less unavoidable while working on a work top. It is, therefore, of the greatest importance to teach the child healthy sitting behaviour and to offer possibilities for *consciously* alternating this posture with an anatomically and physiologically more sound stability. Such a posture could, for example, be adopted while working with a computer, the screen of which should be at eyelevel.

Watching television is a good activity to carry out in the individually preferred sitting posture, once again with the condition that the screen should be placed at eyelevel. After all, the neurophysiological reference posture is one in which the head is in balance on the trunk and the gaze is directed at the horizon. That, then, is where the television should be placed! It is very difficult to teach children sound sitting behaviour, but it is definitely worth the trouble as many complications (for example, slow development of posture abnormalities such as scoliosis) can be prevented or at the least deferred for as long as possible by it.

Just as is the case with adults, along with correct sitting behaviour children with a wheelchair should also have therapy and exercises to keep their muscles at the right length. This is necessary to maintain correct proprioception and to prevent contractures.

Except for the dimensions, good sitting and sound sitting behaviour for children in wheelchairs is no different from that of adults. It should, in fact, be applied even more stringently.

4.4 Seat cushions and pressure distribution

A sitting posture is realised according to the position of the seat and the backrest in space. The seat is defined in the state under load. As was explained earlier, the size and direction of the loads depend on the posture, and the cushion provides for the distribution of pressure over that part of the body carrying the loads. The manner in which the cushion does this depends on the construction of the cushion and the pressure distributing medium that has been used. A general pattern of pressure distribution is given in figure 4-22.

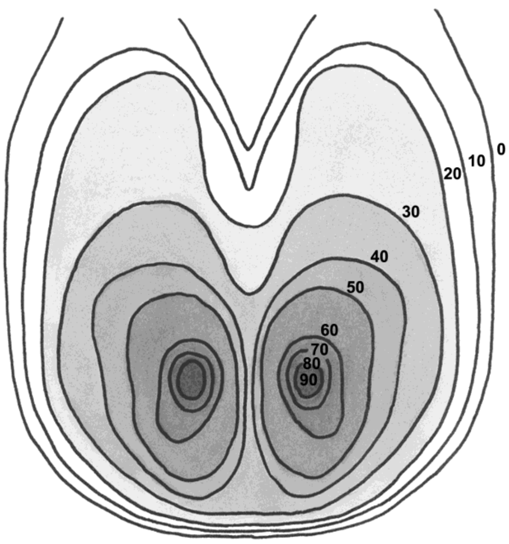


Figure 4-22: Example of a typical pattern of pressure distribution from the screen of the SMS analysis software.

The highest pressure is usually seen under the ischial tuberosities. The term 'pressure distributing' as a property of a seat should in this connection indeed be understood as the ability of the cushion to reduce the pressure under the tuberosities as much as possible by ‘distributing’ it evenly over the rest of the load carrying surface.

The pressure under the tuberosities depends on individual characteristics.
Individual characteristics are:
• the sitting weight of the user: the sitting weight is partly influenced by whether the arms are being used to lean on or not; if they are this makes a difference of approximately 18% to the sitting weight!
• the surface under load or, in other words, the amount of soft tissue: the larger the mass of soft tissue, the lower the recorded maximum pressure under the ischial tuberosities;

• the thickness of the layer of soft tissue under the ischial tuberosities: this layer works as a pressure distributing medium in relation to the tuberosities: the internal pressure close to the tuberosities is higher than the internal pressure just beneath the skin;
• the position of the pelvis, both in the sagittal and in the frontal plane;
• the muscle tension in the buttocks;
• the shape of the ischial tuberosities: asymmetry, bone excrescence, and a surface that is not smooth will all lead to pressure increase;
• posture anomalies that lead to asymmetry.

Internally, the pressure directly under the ischial tuberosities is higher than the pressure that is measured directly beneath the skin. Soft tissue and skin form a pressure distributing layer, as it were, in relation to the tuberosities. It is important to realise that all buttocks have their own pressure distributing capacity: this is used to its utmost advantage when the buttocks maintain their own shape as closely as possible.

Good pressure distribution ensures that the tuberosities are put under the least possible load. People experience this as comfortable. Too much load for too long a period will be experienced as uncomfortable and – under normal circumstances – will act as a warning mechanism. This results in a change of posture. This is usually an unconscious, automatic reaction.
In wheelchair users with reduced sensitivity this mechanism either does not work properly or does not work at all. There will be no automatic reaction when loads are too high or are sustained for too long. This presents a real danger of damage to the tissues. Seat cushions for wheelchair users should afford the maximum possible comfort and should provide the correct distribution of pressure. An optimal microclimate between the cushion and the buttocks is also necessary. Proper heat and moisture regulating properties in the cushion can provide this.
In actual fact, all of these measures are still *insufficient* if the wheelchair user is not aware of the risks they run of developing decubitus and therefore does not take additional measures to prevent it. Even with the best cushions the internal pressure under the tuberosities is still too high to be harmless after long periods. The keywords here are *dynamic sitting behaviour*. Dynamic sitting behaviour provides varying loads and this is necessary in the fight against decubitus.

The only reason why people who spend all day long sitting on barely upholstered office chairs without developing decubitus is movement, dynamic sitting behaviour.

There are many sorts of special cushions available for sale, the so-called anti-decubitus cushions which are claimed to realise exceptionally good pressure distribution. The author’s own cushion research has shown that this is, on average, somewhat disappointing and that conventional foam-based cushions can also provide very good pressure distribution if a number of initial points are adhered to. The shape of the supporting construction under load plays an important role in this, as was discussed earlier. Hammock seat constructions have a beneficial effect on the pressure distributing properties of a layer of foam if used in conjunction with it.

Figure 4-23: Example of a preformed support construction for a foam cushion.

A cover can have a great influence on the pressure distributing capacity of a cushion. Generally speaking the pressure under the tuberosities will increase as the cover becomes 'stiffer'. The explanation for the influence of the cover on the pressure distribution result can be found in the so-called ‘hammock effect'.
The hammock effect can be explained by the fact that there is a difference between the projected surface of the buttocks before load and the actual surface under load.
This difference must appear from somewhere as one 'sits down'. In figure 4-24 we can see that it comes from the sides of the cushion.

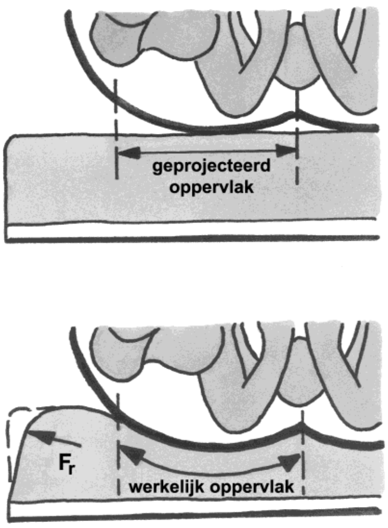


Figure 4-24: The difference between the projected surface and the actual surface.

The distortion of the foam in the horizontal direction that occurs here produces a reactive force that resists this distortion: this ‘tensile stress in the surface under load' wants to pull the surface under load flat again. This tendency prevents the surface under load from completely following the shape of the buttocks. This produces an increase of pressure under the tuberosities, because there the shape of the buttocks is most flattened by the tensile stress in the cover.

The essential difference between foam cushions on the one hand and air, water or liquid gel filled cushions on the other can be found in the relation between depression and reactive force. Foam reacts like a compression spring: the reactive force increases as the depression becomes greater. In air and liquid filled cushions there is hardly any reactive force during depression and equilibrium is established fairly suddenly. Air pressure or hydrostatic pressure occurs in the system and is determined by the magnitude of the load L and the size of the area under load A

As a formula: p = L/A

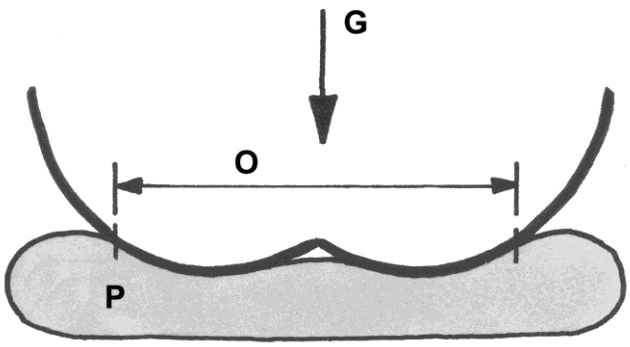


Figure 4-25: Pressure p =(L/A .

In practice this means that equilibrium occurs depending on the construction of the cushion and the extent to which it is filled: the amount of air or water that is in the system, the size and shape of the buttocks and the magnitude of the sitting weight.

This pressure would, in principle, form a uniform external load if there were no tensile stresses occurring in the outer layer due to air pressure or hydrostatic pressure. This tensile stress has the same effect as the 'hammock effect' described earlier and prevents complete adaptation to the shape of the buttocks.
The magnitude of the tensile stress that occurs in the outer layer of this sort of pressure distributing medium is in direct relation to the magnitude of the air pressure or hydrostatic pressure p in the system. The pressure p in the system should therefore not only be kept low in view of the pressure distribution but also in order to keep the hammock effect as low as possible.

The negative effects of the tensile stresses in the surface under load are resolved in actual practice by dividing the surface into small areas. In the case of foam, this is done by making vertical cuts which cause the horizontal correlation to be interrupted and reduced; in the case of air cushions, many smaller balloon-like elements are created that are connected to each other. The material properties of the outer layer, in combination with the manner in which these cells deform, will influence the extent to which edges which can result in a local increase of pressure occur.

One problem with these cushions is the lateral stability. This can be resolved by the creation of left and right compartments that can be closed off from each other. This should be done as soon as one is sitting symmetrically on the still open system. In a laboratory setting with a test buttock with built-in pressure sensors it proved impossible to reproduce measuring results with this sort of cushion. During the same experiments it was seen that the relationship between interface pressure and the actual internal pressure under the tuberosities was much more favourable with this sort of cushion than with foam cushions. Where with foam cushions there was a difference of factor 2, with the type of air cushion described this was a factor 3. That is to say that the internal pressure in the first case is twice as great as the measured interface pressure and in the second case three times greater.
One could also conclude that the interface pressure meters presently available give favourable measurements for the interface pressure of this sort of air cushion.

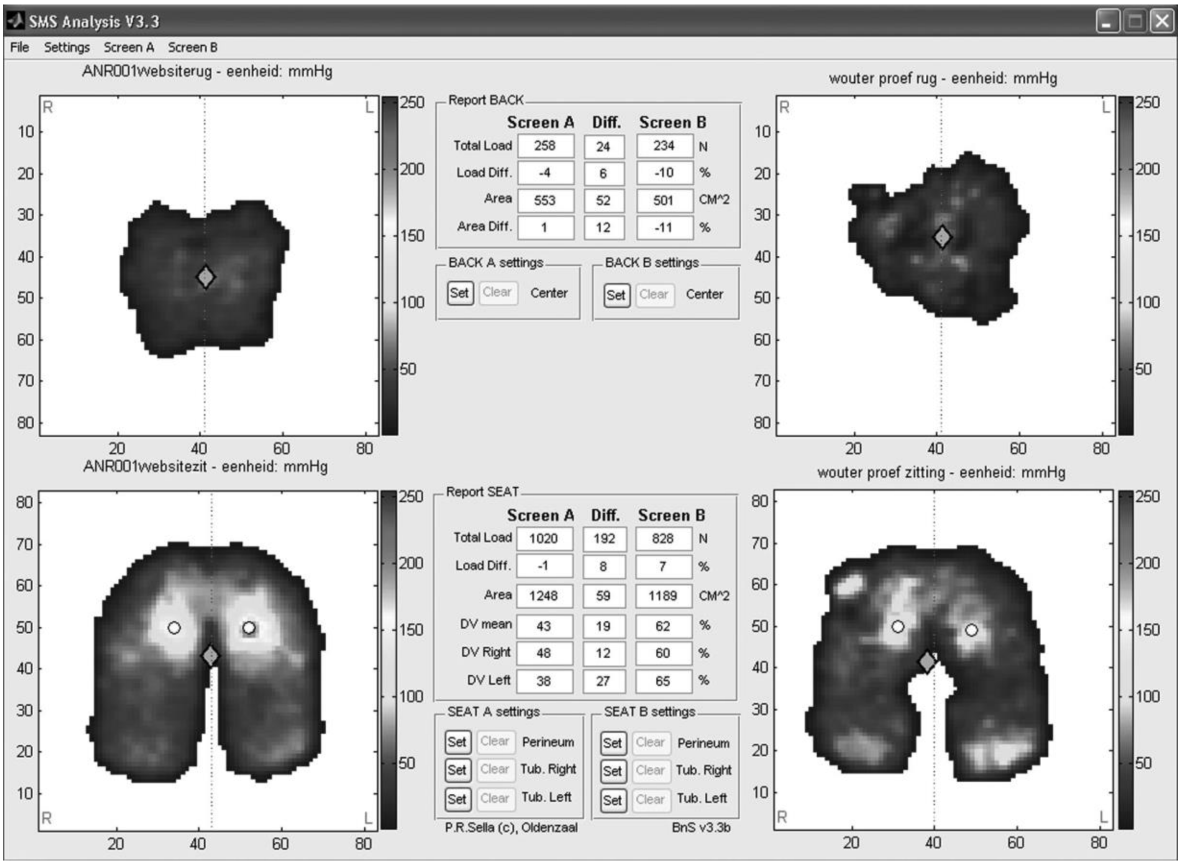


Figure 4-26 Comparable results from a measurement of sitting pressure using the SMS analysis software.

Measuring and interpreting interface pressure with so-called pressure gauging mats is, therefore, a difficult matter. Pressure gauging mats with a high resolution give the results of approximately one thousand cells. The question is how two different results should be interpreted, if we take into consideration the fact that the precision of this sort of mat is fairly low. Software has recently been developed, based on the essentials of pressure distribution, which uses representative index ciphers to allow proper comparison of pressure distribution results. The pressure distribution PD is calculated at the location of the tuberosities and expressed as an index cipher on a scale from 0 to 100: the lower the load on a tuberosity, the higher the cipher.

In the SMS analysis software that has been developed, as well as the use of relevant index ciphers for pressure distribution, a lot of attention has been paid to the ease with which two sets of measurements can be compared and interpreted.

4.5 Analysis of the properties of wheelchairs

A wheelchair is a highly complicated product. The user wants a wheelchair that is suitable for a very wide variety of activities, that can be taken everywhere, it must be easy to put in the car and it must not be in the way when not in use: in short, the user is looking for the impossible. As the impossible cannot be delivered, a wheelchair (concept) is always a compromise.

The desired properties for a wheelchair often cancel each other out. The need for a wheelchair propelled by the user's arms to run lightly is at odds with the necessity for a certain amount of stability. The addition of a camber in the drive wheels to improve the steering aspects and to protect the hands results in extra width. Certain properties have to be relinquished to be able to keep other properties in the concept simply because the one cancels the other out in the realisation.

In the matter of sitting posture, there is an area of tension between a sound, stable sitting posture and a posture from which it is easy to make a transfer.

Figure 4-27: Non-folding wheelchair C-Rex with electrically driven tilt adjustment and individually adjustable back support: in the transfer position and in a position for a stable sitting posture.

Making a transfer is easiest when the seat of the wheelchair is horizontal. This is at odds with the ideal equilibrium of forces in the seat in a stable posture, as there the backrest inclination is at least 115º. With a horizontal seat one would gradually slide out of the chair and frictional forces would occur in the seating surface to prevent this happening. For equilibrium of forces without friction a seating angle has to be approximately 12º but that makes a transfer more difficult. In the traditional folding wheelchair the compromise was clearly on the side of the transfer; this wheelchair was, however, intended for only very short periods of use.

Figure 4-28: Traditional folding wheelchair: optimised for transfer and suitable for very short periods of use. The seating angle, angle φ is approximately 0º, the backrest inclination, angle(φ+α) is approximately 105º.

Adjustment mechanisms that can alter a stable sitting posture into an optimal transfer posture 'cost' extra construction elements. These take up space, add extra weight and stand in the way of other fundamental constructions such as, for example, constructions that would make it possible to fold or compact the wheelchair. Extra weight means that the wheelchair is heavier to propel and heavier to lift into the boot of a car.

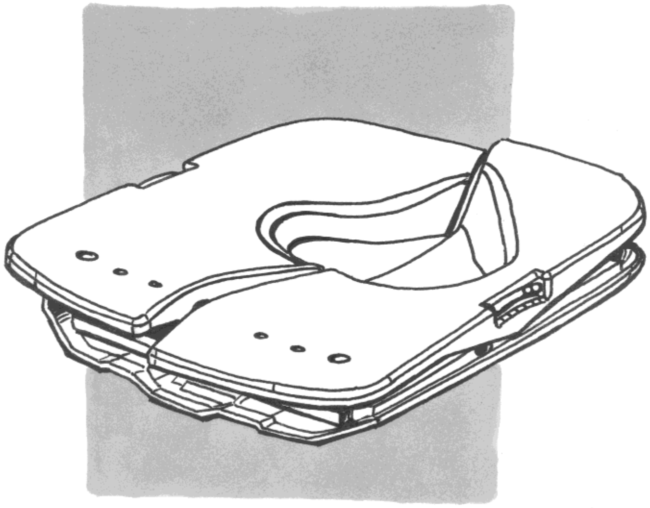


Figure 4-29: Solution for the transfer problem in a classic wheelchair: the tilt cushion

One solution for this problem is the tilt cushion developed in 2006. This cushion does not only provide a facility for making a transfer from a horizontal seat but also - automatically – creates an evenly distributed load on the seating surface that is not dependent on the precise adjustment of the leg rests. This results in the full utilisation of the seating surface and therefore optimisation of the pressure distribution.

Conversely, constructions to enable one to fold or compact the wheelchair are so definitive for the design that it becomes very difficult to realise a mechanism for posture adjustment within that design.

Figure 4-30: C-Rex with electrically driven tilt adjustment in a stable sitting posture and in an individually preferred posture arrived at by tilting the entire posture approximately 8º backwards.

Electrically driven wheelchairs have more construction facilities to enable realisation of a mechanism to allow the user to adjust their posture support.

As it is often not possible to realise all of the desired properties for a wheelchair at the same time, clear choices should be given high priority in the treatment of each separate case. One should realise that that which is most difficult should be given the highest priority. An anatomically sound, stable sitting posture should be at the top of the list of priorities for normal, long-term wheelchair use. For related problems such as, for example, making a transfer, additional solutions should be created, such as, for example, the application of a tilt cushion.
Recently, a patented back support system came onto the market with which anatomically sound stability can easily be realised in a more or less traditional wheelchair concept. In this back support system, the support for the region of the back above the lowest part of the small of the back has been separated from the support below that point. The back support is set at 115º above the small of the back and is adjusted to the individual height. The section of the support for the lower region of the back is adjusted to fit the individual user. For a comparable – standard – solution, see also figure 3-9: DD04.

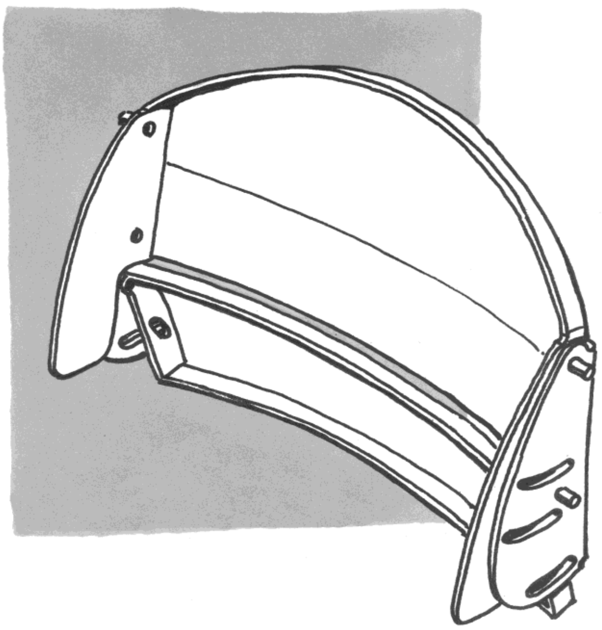


Figure 4-31: Prototype of an individually adjustable back support that can be used to facilitate an anatomically sound, stable sitting posture in a classic wheelchair.

The effect of using this sort of back support can clearly be seen in figure 4-32. The line drawing shows the original situation, the photo shows the anatomically sound, stable resulting situation. The difference would seem to be small but is essential for the way in which the spinal column sustains the loads, for the pressure on the internal organs and for the position of the head.

Figure 4-32: Optimisation of the sitting posture by manipulating angle φ and angle(φ+α) to achieve a sitting posture with anatomically sound stability.

Using the biomechanical model in figure 4-33, one can clearly see what is actually happening.

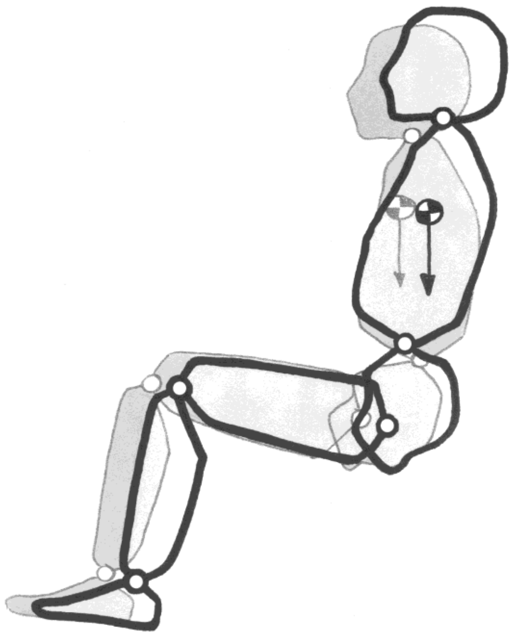


Figure 4-33: Biomechanical explanation of figure 4-32: the difference between anatomically sound stability and anatomically unsound stability (the figure in broken lines).

4.6 Summary and conclusions

Sitting in a wheelchair leaves the user susceptible to a number of complicaties due to their motory functional impairment and the enforced nature of the use of the wheelchair. These complications can be prevented or resolved by active or passive simulation of natural sitting behaviour combined with the optimisation of the user's seating conditions.

In natural sitting behaviour there is an observable strong desire to relax. This is achieved by choosing a stable posture as soon as one's activity allows. An anatomically sound, stable posture begins when the functional backrest inclination, angle($\varphi+\alpha$) is 115°.

Sitting in a wheelchair should follow the normal set of 'rules' for 'sound sitting posture' and should afford the maximum amount of 'comfort', because the warning mechanisms for over taxation are often impaired or lost in the case of wheelchair users.

The basic sitting posture in a wheelchair can then be nothing other than an anatomically sound, stable sitting posture with an angle($\varphi+\alpha$) > 115° , an angle α of approximately 103° and with an individual support for the back. That means that the back support should afford sufficient space for the buttocks and its position should be adjustable in relation to the lowest part of the small of the back.

If a wheelchair concept only affords one sitting posture, then the anatomically sound basic posture should be seen as a compromise between an optimal transfer posture with a seating angle, angle φ of 0º, and an average individually preferred posture with a functional backrest inclination, angle($\varphi+\alpha$) of approximately 123°. Wheelchairs that can be adjusted by the user should at the very least be able to move between a transfer posture and a relaxed preferred posture where the size of angle α is adjusted to the stable posture, that is angle α is 103° - 105°. By continually adjusting one's posture to suit one's activity, the necessary dynamism is introduced that has a preventive effect on the development of decubitus. The body is, after all, not suitable for long-term static loads, it is both physiologically and neurophysiologically dependent on movement. Movement entails changing the loads on the body. Movement is also necessary for conscious and unconscious perception, and conversely, perception depends on movement.

Neurophysiologically seen, the position of the head in balance on the trunk with the relaxed gaze directed at the horizon is the reference posture for all manipulations. With the head in this position the body can be controlled with the most precision in carrying out activities. The relaxed preferred posture with a functional backrest inclination, angle($\varphi+\alpha$) of 123° is indeed the basic posture for wheelchair users with an impaired warning system and/or an impaired control system in the brain. With this posture as starting point the necessary movements or (small) changes of posture can be realised either actively or passively.

The pressure distributing properties of the supporting elements play a role in the manner in which the reactive forces are transmitted to the seating surface. Frictional forces in the seating surface should be avoided by ensuring a correct sitting posture, a correct relation between seating angle φ and hip angle, angle α.
Reducing the load in the areas around the ischial tuberosities as much as possible is the essence of good pressure distribution and will prevent the onset of decubitus.

It has been shown that the easier – read: with the less resistance, - a cushion adapts itself to the shape of the buttocks, the better the pressure distribution. The shape of the support construction of the cushion plays an important role here. A hammock generally gives a better result than a flat plank.

As well as the pressure distributing quality, good moisture and heat regulating properties are important comfort determining properties for a cushion: if these are sufficiently efficient they will also aid in the prevention of the onset of decubitus.