Stellingen

behorende bij het proefschrift van H.A.M.Staarink
Sitting posture, Comfort and Pressure; assessing the quality of wheelchair cushions.

7 december 1995

1 De voorzieningen voor de invaliden van vandaag zijn de voorzieningen voor de validen van morgen. (Klapwijk 1972)*

2 Funktioneel en technisch onderzoek naar de kwaliteit van hulpmiddelen is een kostbare, doch kostenbesparende aktiviteit.

3 Vergelijkend warenonderzoek leidt meestal niet tot produkt optimalisatie.

4 De ergonomie van beeldschermwerk behoeft dringend een fundamentele, biomechanische en neuro-fysiologische benadering.

5 Het dragen van lichte lasten op het hoofd zou in de westerse wereld, uit een oogpunt van preventie van rugklachten, bevorderd moeten worden. (Tournier 1973).*

6 Bij de beoordeling van kantoormeubilair vormt de drukverdelingskwaliteit van de zitting totnutoe slechts een subjectieve maatstaf.

7 Om het fenomeen decubitus te doorgronden, is bij onderzoek van de relatie zitting-achterwerk onevenredig veel aandacht besteed aan het achterwerk.

8 Een keuringsregeling is de aangewezen methode om de kwaliteit 'anti-decubitus' van hulpmiddelen te beschermen.

9 Ieder zittend achterwerk heeft zijn eigen unieke drukverdelingskarakteristiek.

10 De interne druk in het weefsel direct onder de tubera is tenminste een faktor 2 groter dan de zogenaamde interface pressure en tenminste een faktor 3 groter dan de capillaire druk.

11 De invloed van het drukverschil tussen twee plaatsen in levend weefsel op weefselvervorming en op eenzijdige interstitiële vloeistofstromen zou onderzocht moeten worden.

12 Vocht is als risicofaktor van het ontstaan van decubitus wel een veelgenoemd doch weinig onderzocht fenomeen.

13 De positieve invloed van een zogenaamde hangmat in een rolstoel op de drukverdelende werking van een kussen is totnogtoe onderschat.

14 Custom contoured kussens dienen opgebouwd te worden vanuit een custom contoured draagconstructie.

15 Het vastleggen van de drukverdelingskwaliteit van een kussen in een getal op de schaal van 0 tot 100, in combinatie met een minimum waarde voor een gedefinieerde gebruikersgroep, levert doeltreffend gereedschap voor gevalsbehandelaars.

* persoonlijke mededeling

Sitting posture, Comfort and Pressure;

assessing the quality of wheelchair cushions

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Contents

On account of the relationship wich is often drawn between sitting pressure and capillary bloodpressure in addition to the fact that bloodpressure is still expressed in terms of mmHG, the unit of measurement used throughout this book is mmHg.

Conversion table for units of pressure

1 Pa	= 1 N/m2
1 MPa	= 1 N/mm2
1 MPa	= 0.075 mmHg
1 mmHg	= 13.333 N/mm2

0.1 Background and objective of the study

This study is based in large measure on a survey into the quality of wheelchair cushions carried out between 1986 and 1993 on behalf of the Provisions Department of Gemeenschappelijke Medische Dienst (Joint Medical Service). The tests on the cushions were performed by the TNO Textile Centre in Delft during 1991 and 1992.
The results and analyses have been published at an earlier stage (1992) as preliminary findings in the following three reports:

- **Basisboek Voorzieningen Verplaatsen,**
  Keuzeproces beschrijving en produktinformatie Rolstoelkussens
  (describing selection process and product specifications of wheelchair cushions)
- **Basisboek Voorzieningen Verplaatsen,**
  Kennisboek Rolstoelkussens
  (analysing the phenomenon of pressure-distribution in wheelchair cushions)
- **Voorstellen voor de beoordelingscriteria voor rolstoelkussens**
  (describing proposals for assessment criteria for wheelchair cushions)

To a large extent Chapters 1 and 2 of this thesis are based on;

- **Het zitboek, zithoudingsproblematiek in rolstoelen.**
  (A analysis of sitting posture problems for wheelchair-users)

This book was commissioned by the GMD as a text book for therapists and other experts involved in the assessment of wheelchair-users and was published in July 1995 by De Tijdstroom, publishing company in Utrecht. The book is based on study of literature, small-scale experiments and measurements in combination with expertise and experience acquired as a result of training courses given to GMD wheelchair advisors during many years. It has been realised in cooperation with F.A.C. van Haaster and A.G. Tournier.
Chapters 1 and 2 create the context in wich the concept of comfort can be understood and the framework in wich the cushion, withregard to its role in the sitting posure, can be properly isolated as an object of study.
The primary practical objective of the survey into the quality of wheelchair cushions was to provide useful product information to advisors in the field so that the most appropriate choices can be made and cushions can be deployed in the best possible fashion. Inherent to this is that a good understanding of pressure-distribution, one of a cushion's most important features, has to be

developed and presented. This was a secundary objective of the study. This latter objective can be achieved by providing answers to a number of questions: What is the effect of the different cushion properties and different cushion systems on the pressure distribution? How can a cushion be optimized for a specific individual and what is the interplay of parameters?
At the same time answers to these questions produce design criteria for the development of cushions both for the individual wheelchair user as well as for defined user groups.
The survey must take place under laboratory conditions and the tests must be repeatable. Assessment criteria for the different selected properties of cushions should be developed in relation to defined user groups, the third objective of this survey.

1.0 Sitting

Until quite recently sitting was deemed a social prerogative enjoyed by a privileged few. The entitlement to take up a seated position provided evidence of a person's standing. The act of sitting is associated with status and power, borne out by such terms as the throne, to sit in judgement, and a professor's chair. The design of furniture was often intended to reflect the status of its user. This is still the case today. Unfortunately the functionality of such furniture is occasionally still in inverse proportion to its status. The annual Queen's Speech to parliament provides visible proof of such physical discomfort.
The sitting position at work has a short history. By only a gradual process did the top echelons of industry and commerce permit their subordinates to carry out work in a seated position. Long after office clerks had been permitted to trade in their reading standards for office chairs at desks, seating on the workfloor remained an unheard-of luxury. This process of change continues today. We can still observe traditional expressions of status in the design and use of present-day furniture. Nowadays important facets of sitting include upholstery fabrics and the ability to vary posture. Recumbent and relaxed sitting postures still appear to be the privilege of the few rather than of the many.

Interest in sitting postures at work developed when pressure for more efficient working methods began to take precedence over the social aspects of sitting. At the same time much physical work has been substituted by mental exertion, initially as a result of industrialisation and more recently with automation, i.e. work at visual display units (VDUs).
In order to perform a task efficiently, also during mental work, an optimum working posture is required which should take into account long-term health risks. Literature with regard to sitting therefore tends to concentrate on this aspect and is dominated by studies concerned with sitting postures in relation to productivity: office chairs, standing aids on the workfloor, and seats in fork-lift trucks and heavy-goods vehicles. In short, these are work situations in which prolonged periods of sitting are demanded, often in the same position This is also the case for school furniture. The studies themselves do not discuss generally comfort in the everyday sense of the word, i.e. comfort as 'adding that little bit extra in order to make living and working more agreeable' - the maximum option. Without wishing to question the objectives of such studies they all tend to define comfort as 'the minimisation of discomfort both in the long and short term', i.e. the minimum option.

The first chapter of this book presents an introduction to the most important factors affecting sitting and comfort. The aim of this chapter is to try and understand the perception of comfort and define it in quantifiable terms. This 'generalised know-how' will be developed further in the next chapter with specific reference to wheelchair sitting. Aspects of sitting behaviour and perception of comfort which have been analyzed in this framework will be discussed in greater depth and expounded upon for this special situation. The specific role played by supporting elements in the perception of comfort will be singled out in later chapters for more detailed examination.

1.1 Sitting posture

Sitting is characterised by a sitting posture. There are all sorts of sitting postures ranging from squatting positions to those where the individual is almost standing. Posture holds a central place in the study of posture. Sitting disorders are usually the result of an incorrect sitting posture, and can often be rectified by following sound advice on how to adopt a correct sitting posture. In order to analyze sitting properly the term 'sitting posture' first needs to be defined. A sitting posture usually results from a 'supporting element' (i.e. a chair) which 'affords' the user a sitting posture. The position of the supporting planes in space often provides an approximate representation of this sitting posture. However it is known that a wide range of sitting postures can be assumed in a chair, e.g. an upright posture which follows the contours of the supporting planes; a symmetrical leaning back posture; an asymmetrical, skewed leaning back posture, etc. In any given auditorium one would be hard pressed to find any two people with the same sitting posture and one would find after a while that each person had adopted a *different* posture. For this reason it is important to arrive at a precise definition of 'sitting posture'.

Sitting posture can best be defined from a bio-mechanical and physiological standpoint, since these disciplines utilise a nomenclature for interpreting specific postures in relation to activities and for analyzing disorders relevant to posture.
Since the human frame is, simply stated, a complex interplay of bones and muscles we first need a degree of schematisation in order to arrive at a clear definition of sitting posture.
The model of the body which we have adopted for this purpose consists of a chain of motile bodily segments, interlinked, but each possessing a rigid structure. Each segment has its own dimensions and mass.

We can see in figure 1-1 how the model is derived from an x-ray picture (Diffrient e.a.1974): the model consists of a side view only (the sagittal plane):

- the ankle knee and hip joints are represented as simple hinges;
- the pelvis and upper trunk are regarded as separate elements.
- the upper trunk shows a pivot point in the axillary region. This enables us to simulate a kyphosis, an enlarged backward curvature of the thoracic section of the spine; this schematisation is also used in the so-called Kieler Puppe.
- the lumbar and thoracic parts of the spine are connected by a single pivot point; this drastic simplification of reality facilitates a better bio-mechanical analysis;
- the head is linked to the cervical part of the spine by a single pivot point;
- the mass of the bodily segments is deemed to be concentrated in separate centres of mass.

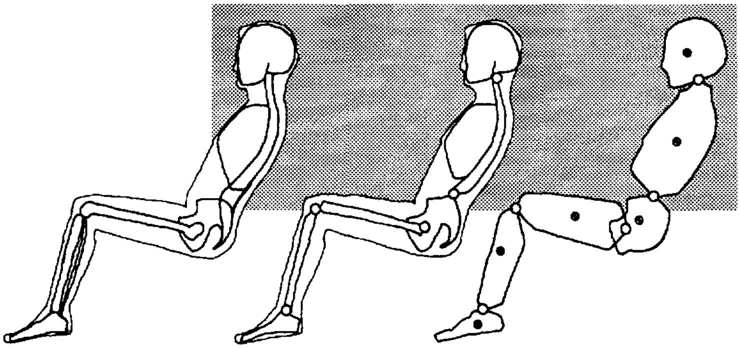


Figure 1-1: Derivation of the bio-mechanical model developed.

In the model it can be seen that there are no muscles included around the joints. This does not mean the assumption has been made that no muscle power is present. The *moments*, which operate on the pivot points in order to achieve a balance, represent the loads acting on *muscles, tendons and ligaments* around the joint. The *reaction forces* in the pivot points form the loads on *joints*.
If, in a certain posture, balance is achieved without the need for moments to operate on the pivot points, this means that the posture, in theory, can be maintained without any muscular exertion. The model can simply be described as a collection of volumes, each with its own mass and centre of mass, linked together by joints. Figure 1-2 indicates the principal dimensions and masses of the segment components of the bio-mechanical model which has been developed. The data have been borrowed from Damon, Stoudt and McFarland (1971) and a later refinement by van Buchem (1973). The purpose of the model is to enable an analysis of the principles in the bio-mechanical aspects of sitting posture. 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, an acceleration of gravitational forces begins to take effect *at that point*. This is also true for the schematised position of the different pivot points.
The model can be used to adequately define a sitting posture, to gain an understanding of the size and direction of the internal and external loads, to optimise sitting posture and to examine the degree of influence that reduction or loss of muscle function has in the ability to maintain a posture.

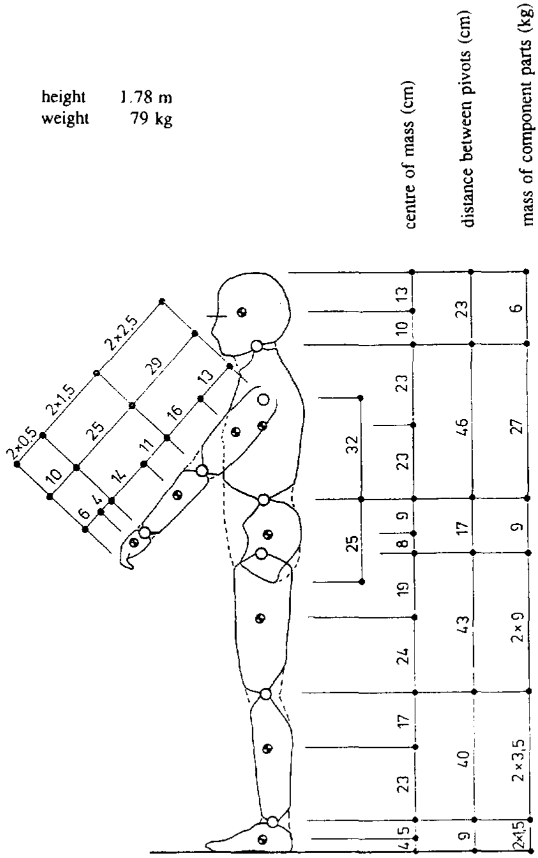


Figure 1-2 : Principle dimensions and masses of segment components of the bio-mechanical model of the human body in cm. and kg.

A sitting posture is defined by the mutual position of the bio-mechanically and physiologically important parts of the body in relation to each other and the general position in space.

In order to establish a link with the sitting posture which is 'afforded' by the chair and to carry out the work pragmatically, the planes of contact along the bodily segments are adopted as reference planes and to this purpose the angles of the different bodily segments are defined in relation to each other. The position of the thighs is defined in relation to the horizontal plane thereby enabling the position in space of the different bodily segments to be calculated. The classification and definitions used in this study are a refinement of those used by the GMD for wheelchair evaluation since 1978 (Staarink 1978). The basic sitting posture can therefore be defined by the angles ϕ, α, β, γ and δ . Unfortunatally, there is no general agreement to be found in literature on these definitions.
In figure 1-3 the angles defined are illustrated.

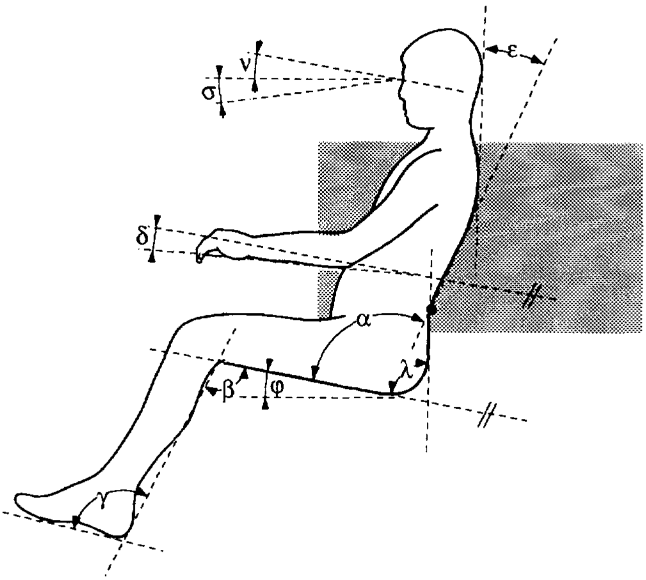


Figure 1-3 : Classification of the nine angles which determine the sitting posture in the sagittal plane.

Angle ϕ represents the position of the plane of contact on the underside of the thighs in relation to the horizontal. An angle above the horizontal plane is given a positive value. Since all the other angles are defined in relation to each other, angle ϕ determines the actual position of the body in space.

Angle α represents the position of the plane of contact on the back of the upper torso segment in relation to the plane of contact on the underside of the thighs. This definition implies that the position of the upper torso segment in space is determined by the *angle* $(\phi + \alpha)$, also known as the absolute back angle. The size of the angle $(\phi + \alpha)$ indicates respectively the degree of torso balance and the amount of energy necessary to maintain this posture.

Angle λ represents the position of the pelvis in relation to the thighs. 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.

Angle $(\alpha - \lambda)$ describes the *shape of the lumbar region* whilst the sitting posture is maintained. If the angle is positive the spine displays a lordosis. The size of the angle indicates the degree of the lumbar lordosis. If the angle has a negative value the spine shows a kyphosis, the size of the angle indicating the degree of the kyphosis.

The shape of the lumbar region can be defined for each individual by *lumbar depth* present whilst in a standing position. This is the *greatest* depth which can be measured from the plane of contact along the thoracal and sacral part of the back in the direction of the lumbar part of the spine.

Angle ϵ represents the position of the head in relation to the torso and is defined by the angle which the plane of contact on the back of the head and the most extreme point of the thoracal back makes with plane of contact along the thoracal part of the back. Angle ϵ represents total flexion of the head, neck and upper part of the torso segment.

The *angle* $\{(\phi + \alpha) - \epsilon\}$ represents the position of the *head and upper torso* in relation to the horizontal plane. This is the angle which the plane of contact on the back of the head and the most extreme point of the thoracal back makes with the horizontal plane. This angle indicates the load on the upper back muscles in maintaining the sitting posture.

Angle v represents the position of the *head* in space more clearly than the angle $\{(\phi + \alpha) - \epsilon\}$. The reference plane which defines the position of the head is known as the Frankfurter plane and is the plane which runs through the lower edge of the eyes (the orbital points) to the upper side of the entrance to the ear (the tragus). Angle v is defined as the angle that the Frankfurter plane makes with the horizontal plane. Any angle above the horizontal has a positive value. Angle v is about $10°$ for someone in a standing position whose gaze is directed towards the horizon (Burandt 1978). De Wall et al. (1991), in their study, define the 'o' position of the head as when a person's gaze is directed to $15°$ below the horizontal plane.

Angle σ is the angle which the line of sight follows in relation to the horizontal plane. Any angle below the horizontal plane has a negative value. The size of

angle σ is determined by angle ϵ and the flexion of the head and is partly influenced by the upwards or downwards rolling of the eyeballs. The so-called 'easy eye movement' covers a range of approx. 15°. We can surmise from Burandt's figures (1978) that a *relaxed* gaze makes an angle of 15° to 20° in relation to the Frankfurter plane.
Angle δ represents the position of the forearms. This is defined as being the angle between the plane of contact on the underside of the forearms and the plane of contact running along the underside of the thighs. Figure 1-3 illustrates an angle δ which has a positive value. When angle δ is the same as angle ϕ, then by definition the forearms assume a horizontal position.

Angle β represents the angle between the line running from the back of the knee to the rear of the heel and the plane of contact on the underside of the thighs.

Angle γ defines the position in the sagittal plane of the ankle joint as the angle between the underside of the foot and the line running from the back of the knee to the rear of the heel.

These definitions of the nine angles in the sagittal plane enable us to define with sufficient accuracy and to quantify the (sitting) posture of the body for the purpose of this study. Asymmetric sitting in relation to the mid sagittal plane, for example when one leans sideways, requires a separate definition.

In theory the 'sitting posture' afforded by a chair can be defined and ascertained using the angles ϕ, and angle α and λ. To this end the chair needs to be measured in its occupied condition using a test dummy representing a seated individual. For a wheelchair the angles β and γ can be included. Whenever the body is able or given the opportunity to follow these 'angles' precisely, the body will quite literally assume this posture. If this is not possible or this does not occur then in theory another posture results.

1.2 Sitting behaviour

Whenever a person's sitting behaviour is observed the individual appears inevitably to adopt similar postures for similar activities. This fact has been established in literature on the subject of sitting (e.g. Grandjean 1969), but can also be verified by the results of a simple training exercise in which a group of healthy adult students was asked to adjust a wheelchair with variable angles ϕ and α for three different activities. (A specific lumbar support was not available). The three activities comprised the following:

- 'active' : working at a table or propelling the wheelchair;
- 'semi active' : watching television, or in conversation;
- 'resting' : taking a nap in the sitting position.

Figure 1-4 shows how the seat plane (angle ϕ) and the backrest (angle α) were adjusted. The sides of the rectangles indicate the range of standard deviations away from the centre.
The angles were measured in relation to the wheelchair's frame and not as loaded planes of contact in relation to the seated person, meaning that only a comparable interpretation can be ascribed to the values, which is no more than was here intended.

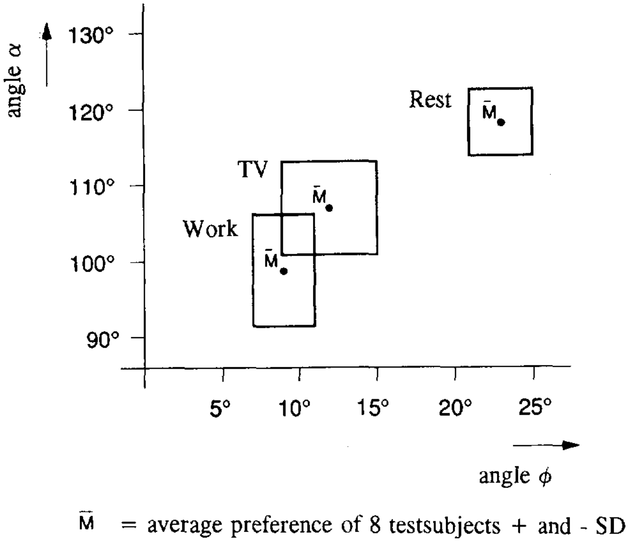


Figure 1-4: Adjustment of angle ϕ and angle α in relation to a designated activity in a training exercise (n=8).

It can be established that the more passive a sitting posture becomes, the greater the degree to which angles ϕ and α are adjusted and that there is an increasingly positive, somewhat curvilinear correlation between angle ϕ and angle α. The adjustment was not made on the basis of any understanding of sitting postures, but on the basis of the user's experience of comfort: after all, individuals will always prefer a 'comfortable' posture to an 'uncomfortable' experience. Individuals are probably not consciously aware of the level of muscle exertion necessary to maintain the posture, the comfort areas of the joints, skin sensation, the position of the head and the eyes etc.

Two aspects determine the suitability of a specific sitting posture for a specific activity:
- the position of the head in space together with the line of sight;
- the relationship between stability and freedom of movement of the upper half of the body.

In a sense stability and freedom of movement are antagonistic concepts: the more stable a posture becomes as a result of increased support to the upper half of the body, the less the freedom of movement for the head and the arms. The more freedom of movement is required, the more active the posture will have to be with the body having to maintain itself in balance to a greater or lesser degree. Freedom of movement is of less importance for resting postures. A correct level of stability however is important so that the body can fully maintain its position without any noticeable effort and so that the balance is not disturbed by unexpected movements, for instance in sleep.

The line of sight is a major factor determining the adoption of a sitting posture. The gaze is focused on the subject of our attention, for example a report on a tabletop, a computer screen, or the person to whom we are speaking. In an upright working posture the eyes will make an angle of -38° in relation to the horizontal when a relaxed line of sight is adopted, with a standard deviation of 6.3° (Schobert 1981).
The line of sight determines the position of the head in space which in turn determines the position of the head in relation to the neck, the position of the neck and the upper trunk in relation to the rest of the trunk and so on; it is very probable that the most comfortable and least energy-consuming positions between the different bodily segments are more or less automatically adopted on the basis of the functional demands of the specific activity.
For an active sitting posture with a relaxed line of sight measured at -38° the angle ϵ, which defines the position of the head in relation to the trunk, is between 17° and 29° (Grandjean 1981).
Snijders (in de Wall et al. 1991) has calculated that the muscle power necessary to hold the head in position is minimal for a 30° retroflexion of the head in relation to the neutral position. The neutral position of the head is defined by Snijders as being its position with a relaxed line of sight of -15°.
If a backrest is present the size of the angle $(\phi + \alpha)$ indicates the amount of energy which is necessary to maintain the sitting position. The size of the angle $(\phi + \alpha)$ also indicates the required size of angle ϵ for a specific line of sight. The size of angle ϵ can be related to the amount of energy which is required to maintain a flexion of the upper trunk when no support is present.

Table 1-1 follows on from the results gained for the training exercise and gives a more detailed representation of the different sitting posture parameters in relation to different activities. A sitting posture for the various activities is partly determined by individual characteristics such as the shape of the lumbar, thoracal and cervical parts of the back. These characteristics influence the way in which a relaxed position of the head on the trunk is attained. Moreover sitting postures are always dynamic and constantly change. The table can give no more than an indication, a general approximation, of the different parameters and are intended primarily to show the relative effects that the different activities have on the different parameters.

'Transfer' is an activity which is only relevant for wheelchair-users and involves transferring oneself from one seating surface to another.
The figures used in table 1-1 for angle ϕ and angle α correspond to the values observed by other authors, taking into account the different definitions. Angle ϵ, the flexion of the head/upper trunk in relation to the trunk, and angle $(\phi + \alpha)$ are rarely used as important posture parameters. De Wall et al. (1991) calculated the position of the upper part of the trunk by attaching a goniometer to the first and second thoracal vertebra. The angle which is measured is comparable to the angle we have defined as ϵ. The line of sight is determined by a combination of angle ϵ and flexion of the head.
A curious fact in table 1-1 are the postures adopted by reclining cyclists on a recumbent bike, in particular the size of angle ϵ. This angle is realised as a result of support to the uppermost thoracal section of the trunk. The long-term effects of this are unknown. Random enquiries have so far reported no problems arising from this, but this is usually the case when dealing with enthusiasts.

The above-specified sitting postures for the various activities can be characterised as follows:
- a sitting posture necessary for making a transfer:
  angle $\phi = 0°$ or smaller;
- an active sitting posture with active trunk stability,
  angle $(\phi + \alpha) < \cong 100°$, angle $\epsilon \cong 30°$;
  this posture is suitable for activities where eye-hand co-ordination is required;
- a semi-active sitting posture with passive trunk stability,
  angle $(\phi + \alpha) > \cong 110°$ and angle $\epsilon \cong 15°$ to $30°$;
  this posture is suitable for working at a computer terminal,
- a passive sitting posture with passive trunk stability and an active head position,
  angle $(\phi + \alpha) > \cong 120°$ and angle $\epsilon \cong 20°$;
  this posture is suitable for driving , watching television, conversation etc.;
- a passive sitting posture with passive trunk stability and an active head position, achieved as a result of support to the uppermost thoracal section of the trunk,
  angle $(\phi + \alpha) > \cong 140°$ and angle $\epsilon \cong 30°$ to $40°$;

this posture is suitable for riding a recumbent bicycle;
- an inactive posture with non-active head position, angle $(\phi + \alpha) > \cong 120°$ and angle $\epsilon \cong 15°$.

From top to bottom the features of these sitting postures can be summarised as follows:
- increased stability of the sitting posture,
- decreased muscle activity necessary to maintain the posture,
- increased relaxation,
- the decreased likelihood of activities which require eye-hand co-ordination,
- an increased tendency of the line of sight towards the horizon (up to the inactive posture),
- decreased load on the posterior and the spinal column,
- an increased necessity for support to the upper back region,
- an increased necessity for support to the head.

Individuals choose a sitting posture in relation to an activity in terms of sensation of comfort. An explanation of the suitability of sitting postures for specific activities and in terms of comfort can be made on the basis of bio-mechanical and physiological analysis. This will be the subject of the next section.

activity	angle ϕ	angle α	angle $(\phi+\alpha)$ nominal value upper trunk stability	angle ϵ flexion of head/torso in relation to torso	angle $\{(\phi+\alpha)-\epsilon\}$ position of head/torso in relation to horizontal.	angle σ comfort line of sight*
transfer	< 0°	< 90°	< 90°			
working at table: 'aktive' **						
writing: hor. worktop	0° - 5°	90° - 100°	90°	37°	53°	- 58°
writing: inclined worktop	0° - 5°	90° - 100°	95°	28°	67°	- 52°
reading: hor. worktop	idem	idem	95°	35°	60°	- 53°
reading: inclined worktop	idem	idem	95°	28°	67°	- 47°
working at table: 'semi-aktive' ***						
computer screen 1)	3° - 8°	95° - 105°	100°	30°	70°	- 25°
computer screen 2)	idem	idem	105°	15°	90°	0°
eating	idem	idem	105°	20°	85°	- 45° plate
driving a car #	8° - 18°	95° - 110°	110°	20°	90°	0° horizon
watching TV #	10° - 20°	95° - 110°	120°	15°	105°	- 10°
recumbent biking: # touring version: HRB	20°	120°	140°	30°	110°	- 5°
racing version: LRB	25°	130°	155°	40°	115°	- 5°
resting	15° - 25°	105° - 125°	140°	15°	125°	nvt
sleeping in sitting posture	20° - 35°	115° - 130°	155°	15°	140°	nvt

* 'easy eye movement' range is angle σ + en - 15°.

** data interpreted from De Wall e.a. (1991).

*** 1) Directoraat Generaal van de Arbeid (1989).

2) data interpreted from De Wall e.a.(1992): 'Basis assumptions for an optimal working posture: revised edition'.

\# own data

Table 1-1 : Indications for the size of sitting posture parameters in relation to different activities (average values from different literature sources).

1.3 Perception of comfort

Perception of comfort can perhaps best be defined by the lack of discomfort, i.e. unpleasant sensations of pain and pressure in the muscles, joints, and other parts of the body (Dirken 1994). Perception of comfort is partly related to the suitability of a sitting posture for a particular activity.

In order to maintain postures the muscle-skeleton system resorts to constant action-reaction activity on the basis of neurophysiological detections of position which the different parts of the body occupy in space. For a large part the sitting posture determines the way and degree of exertion necessary to maintain the posture. The dynamics of exertion, or the lack of this, in addition to time duration play an important role in the way comfort is perceived.

To a large extent the suitability of a posture for a particular activity is related to the line of sight which is required and therefore to the position of the head in space as well as to the relationship between stability and freedom of movement in the upper trunk.
The suitability of a posture for a particular activity also partly influences the way in which actions, such as pushing, pulling and lifting need to be carried out. The ergonomic principle behind these actions is that they minimise load on the body and certainly do not overload the body's capacity. The general assumption can also be made that objects, when lifted, should be held as close to the body as possible in order to minimise load on the body. The extra load on the body as a result of the different actions performed in the different postures are not considered in the framework of this study. This section deals with the effects of sitting posture on the amount and type of external and internal load on the body and on how comfort is perceived. External load resulting from a sitting posture is distributed as pressure on the body and as such can be observed and experienced. The amount and type of pressure-distribution determine the level of comfort or discomfort. The characteristics of the supporting element, its shape, dimensions and composition determine the way in which this load is distributed on the body. This topic will be discussed in section 1.4 and elaborated on in chapters 2 and 3.

In addition to the loads already specified other factors are present which exert an influence on levels of comfort. In the micro-climatic conditions existing between the body and the supporting element, moisture and heat have an important part to play in the perception of comfort. An increase in skin temperature and a rise in relative humidity will increase a feeling of discomfort. These aspects will be dealt with in subsequent sections.

1.3.1 Neurophysiological aspects of sitting posture

In physiological terms all body postures are achieved by signals from the brain. An essential condition for all action and reaction in posture and movement is the (mainly subconscious) detection of the position which the body or bodily part assumes in relation to its surroundings. The position in space is a dynamic manifestation which is constantly subject to interference from separate movements, made in particular by the arms, or as a result of external forces. These interferences will lead to compensations in posture.
The equilibrium senses, i.e. the vestibular and optical organs, are situated in the head and able to determine the position of the body in space. The neurophysiological reference point for the head is when it is in an upright position with the eyes fixed on the horizon. From this position the head is able to control bodily activities/movements with great accuracy, these having been learnt, i.e programmed, from an early age.
The eyes and the ears have to orientate themselves in relation to gravity in order to determine direction (down, up, right, left) and to distinguish the direction from which sound originates.
The movements of the head in relation to the rest of the body is registered by means of receptors in the cervical region on the basis of muscle tone registration and the position of joints. An example of this is the tonic neck reflex in animals where the body follows the orientation of the head and eyes: when the head is raised its hind legs drop, when the head is bent its front legs drop.
The detection of the position which the body assumes in relation to its surroundings is further brought about through the reaction forces of the supporting elements on the body and the muscle exertion necessary to maintain a posture. Where previously mentioned interferences by external forces are evident, the 'identification' of the nature of the interference is important for the reaction. Experiments by Nasher in a moving tram, where the body - in order to maintain its posture - is required to acquit itself differently under braking conditions, have borne this out. Cognition, i.e. awareness of the consequences of different actions or processes, appears to be an important factor in learning motoric skills (van Cranenburgh 1994).

Motoric activity is fully dependent on the sensory/perceptive capacity which in turn is dependent on the presence of an intact central nervous system.
The sensory/perceptive capacity, in addition to the vestibular reactions from the equilibrium organ, is, amongst other things, made up of:

- interoception, the supply of stimuli from sensors in the internal organ systems;
- proprioception, the supply of stimuli from sensors in the muscle spindle, tendons and joints. The equilibrium organs are often included here.

- exteroception, the supply of stimuli from skin sensors, the ear and the eye.

In maintaining a sitting posture it is primarily the pressure on the body resulting from the reaction forces of the supporting elements which is the dominating factor in determining muscle tone.

In general, movements lead to sensations, whether consciously perceived or not, and sensations form the foundation to movements. A permanent feedback between sensation and self-motion ensures a balance in muscle exertion necessary to maintain the posture in an essential dynamic way. A constant senso-motoric balance is present in all postures and all movements. For nervous systems which function normally this cycle is safeguarded, furthering the neurophysiological learning process which forms the basis to healthy manner of sitting and sitting posture. This results in perception of comfort.

1.3.2 Influence of time on the perception of comfort

When we observe an individual's sitting behaviour we find that an element of variation (motility) is constantly present: the position of the upper part of the body in relation to the backrest can be changed by placing the greater part of the load alternately on the left and then the right buttock; the trunk can also be moved forwards, changing the load distribution on the seating surface; a new sitting posture can be adopted by taking up a new position in relation to the backrest.

These changes in posture are essential not only because of the neurophysiological aspects of the essential dynamics necessary for control and regulation of the postures as described in the previous section, but also on pure physiological grounds: the body appears not to be able to withstand static load. Sooner or later static internal and external load restricts nutrition to the cells, even damaging them in cases of large external loads.

Some nutritional processes such as that of the vertebral discs are based on diffusion which is brought about by alternating load and relief and the resultant pumping action.

The functioning of muscles is based on a continuous supply of combustible nutrients on the one hand and the breakdown of waste products on the other. This is ensured where alternating muscle-contraction and open vascular systems are present.

Most nutritional processes are based on the respective supply of nutrients and discharge of waste products through the various vascular systems. Long-term blockage of these vessels will cause cells to die off.

For healthy, normal functioning individuals with an intact central nervous system, pathologies, such as decubitus, do not occur.

Static load is soon perceived as being uncomfortable. The neurophysiological warning system guarantees the essential dynamics of the load by transmitting stimuli which are perceived as being uncomfortable.

1.3.3 Internal load

Perception of comfort is achieved by the lack of internal overloading. A number of aspects relating to this have already been dealt with in earlier sections.

The load on the cervical spinal column depends on the way and degree to which the back is supported.
The mass of upper part of the body is transferred to the seating plane by way of the spinal column and the pelvis. The most heavily loaded part of the spinal column is the lumbar region.
The magnitude of the load depends on:
- the weight of the upper part of the body and whether or not the arms are supported,
- the presence or absence of a backrest,
- the level of muscle exertion applied to maintain a specific posture,
- the sagittal shape of the lumbar spinal column attained during the sitting posture in comparison to its natural shape when held in a standing position;

this shape in the main is dependent on:
- the mobility of the lumbar spine,
- the position of the pelvis in relation to the trunk,
- the hip angle α,
- the profile and dimensions of the backrest.

Static muscle activity occurs primarily when sitting without a backrest. The posture that an individual adopts determines the location and the intensity of the muscle exertion which is required. By relaxing the lower back muscles a kyphotic back will result and initially give a relaxed sensation. No further muscle activity in the lumbar part of the spine is necessary since the vertebrae in relation to each other have achieved their furthest limit on account of the restricted length of the ligaments. This means that the load on the vertebral discs is high as well as detrimental. The load on the ligaments is also high. In order to maintain the head in an upright position with one's gaze directed at the horizon, extra exertion is placed on the neck muscles. These are otherwise relatively relaxed when the lower back muscles are used to form a concave lumbar back. Muscle activity in various sitting postures is shown as an electromyogram (EMG) in figure 1-5; a higher frequency of recorded current indicates a higher muscle activity.

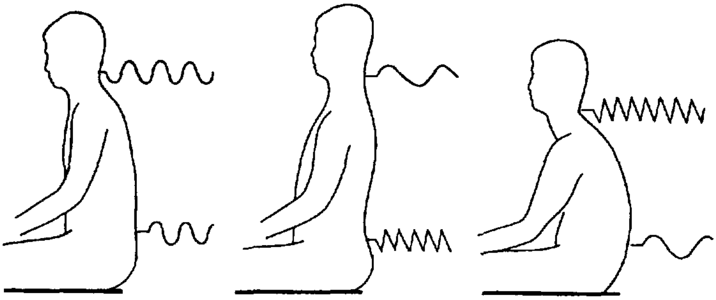
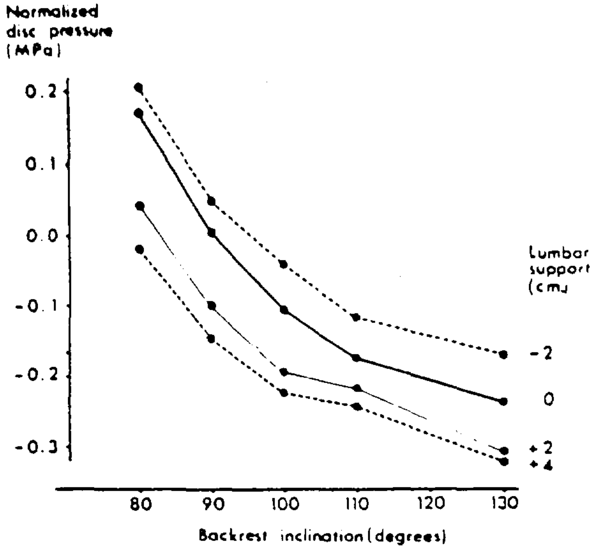


Figure 1-5 : Cervical and lumbar muscle activity for different active sitting postures without a backrest (Schobert 1978).

The load on the lumbar spinal column in relation to the form and size of backrest has been examined in detail by Andersson et al. (1975). They made a large number of *in vivo* pressure readings in the vertebral discs for different sitting postures. A general conclusion which can be drawn from their measurements is that the natural form of the lumbar spinal column results in the lowest pressure and that this further dependent on the posture. Compared to a standing posture an active 'straight' *sitting* posture produces 26% more pressure in the lumbar vertebral discs. The influence of angle α and of the size of the lumbar support on the pressure in the vertebrae disc L3-L4, where angle ϕ is 0°, is shown in figure 1-6.

The influence of angle α is considerable. This is to be expected since the normal load component of gravity of the upper part of the body on the vertebrae disc decreases with an increase in angle ($\phi + \alpha$).
In percentage terms the pressure reduction in the vertebral disc is 16% when angle ($\phi + \alpha$) is 110°. Pressure is reduced by a further 24% with a lumbar support of 2 cm. An explanation for this can be found in the recovery of the original form from the lumbar lordosis which occurs when a standing posture is adopted.



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

Figure 1-6 : The pressure in vertebral disc L3 - L4 as a function of angle α with as parameter the lumbar support depth where angle ϕ = 0° (Andersson et al. 1975).

A sitting posture not only leads to load being applied on the lumbar spinal column but also of course on all bodily joints. The size of the load is not only dependent on the weight of the part of the body to be supported but also on the muscle strength around the joint which is necessary to maintain that part of the body in position. Not only does this require extra force, but it also often supplies a moment of force. Joints show a preferred position which is primarily determined by an equal muscle exertion by those muscles on either side of the joint.

A special form of internal load is the load on the seating plane applied by the reaction forces of the seat. The size and direction of these reaction forces depend on the sitting posture. This problem will be dealt with in the next section. The degree of comfort and the way in which the load is transferred to the seating plane depends on the characteristics of the seating support. This is discussed in section 1.3.5.

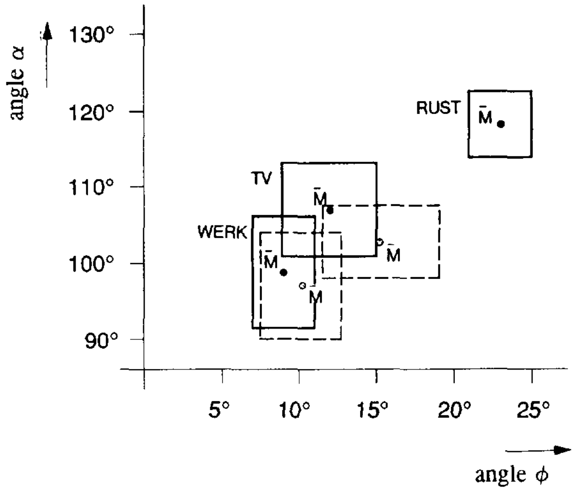
1.3.4 External load

In section 1.2 an initial analysis was given of the sitting behaviour that individuals display in relation to an activity. The results of a training exercise which was aimed at finding a suitable sitting posture for a given activity are illustrated in figure 1.4. During the same training programme the participants were also asked to perform the exercise for the 'work and television posture' but this time with two layers of thin, smooth fabric placed on top of each other in the chair. The effect of using this double layer of smooth fabric (SFD) was that the friction forces between the seat and its occupier, required to maintain the sitting posture were immediately evident.
Friction forces, when applied to the skin, cause shear stress in the softer parts of an individual's posterior, perceived as being unpleasant and which over a period of time leads to a change of posture.
The results of this particular exercise can be seen in figure 1-7.

The figure demonstrates that in using the smooth fabric a new correlation between angle α and angle ϕ results. For both the 'working' posture and the 'television' posture angle ϕ has increased at the expense of angle ϕ . Table 1-2 shows the average values of angles α and ϕ next to each other and also displays the size of the angle ($\phi + \alpha$).

		without smooth fabric	with smooth fabric
Working posture	angle ϕ	9.0°	10.5°
	angle α	99.0°	97.0°
	angle ($\phi + \alpha$)	108.0°	107.5°
TV watching posture	angle ϕ	12.0°	15.5°
	angle α	107.0°	102.5°
	angle ($\phi + \alpha$)	119.0°	118.0°

Table 1-2 : The average values for angle ϕ and angle α for different activities with and without use of the thin, two-layered smooth fabric.



M̄ average preference of 8 testsubjects + and - SD
tests without SFD
tests with SFD

Figure 1-7 : The relationship between angle α and angle φ for different activities with and without the use of a thin, two-layered smooth fabric (SFD).

A number of conclusions can be made from these findings. The use of a smooth fabric does not appear to have an effect on angle (φ + α), but does influence the relationship between them. Angle (φ + α) and the accompanying position of the head appear to be the determining factors in choosing this particular sitting posture. The mutual relationship between angle φ and angle α is determined in terms of the feeling of comfort which results from the lack of frictional forces being applied to the sitting plane.
For the first part of the exercise, i.e. without use of the smooth fabric, there was possibly an element of slight friction which was evidently not perceived as being objectionable for the short period of the test. This is an indication of the influence of time on the perception of comfort.
In order to study the influence of sitting posture on the action of friction forces the results are presented in figure 1-8 of a preliminary study of the connection between the sitting posture, i.e angle φ and angle α, and the degree of the shear and normal stress which results (Staarink 1978). The test was carried out on one female subject with the aid of a Kistler measuring device.

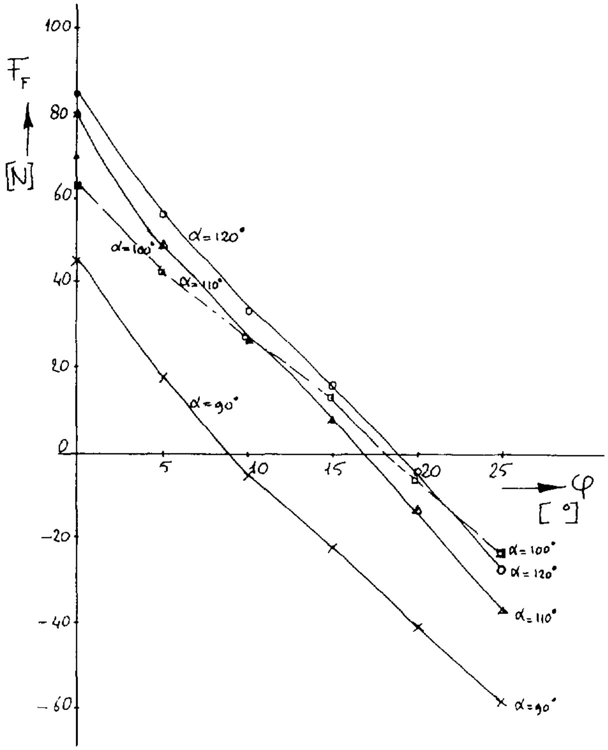


Figure 1-8 : The friction forces F as a function of angle ϕ and angle α for a female test subject of 60.5 kg and 1.72 m. (Staarink, 1978).

With the exception of the measurement taken for angle $\alpha = 100°$, the reason for which is unclear, the results present a consistent picture.

There appears always to be a specific relationship between angle ϕ and angle α, for which the frictional force is 0. When angle ϕ increases, angle α increases. The relationship between these two angles corresponds to the relationship observed in the earlier results of the training exercise and with the results of investigations based on the subjective perception of comfort (e.g. Grandjean 1969). The assumption that individuals will perceive a posture where friction forces are lacking as comfortable and therefore intuitively adopt such a posture appears to be justified.

In figure 1-9 the reactionforces of the supporting elements are presented in balance with the weight of the body W. In this case small frictionforces are necessary to attain the balance. By increasing angle ϕ or decreasing angle α a balance can be achieved without friction forces.

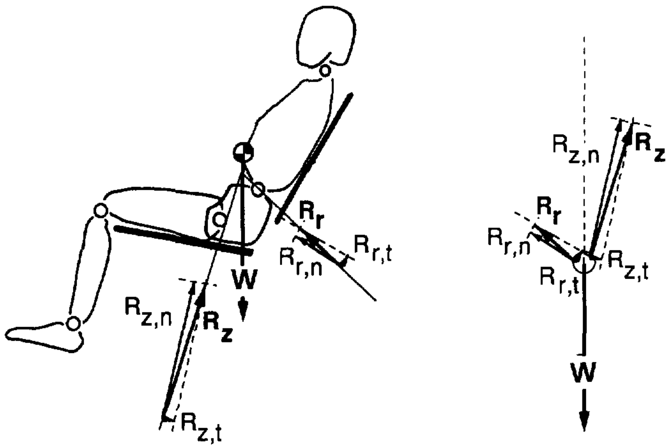


Figure 1-9 : Reaction forces of supporting elements in balance with the bodyweight W (Snijders 1984).

Goossens (1994) has further developed Stumbaum's (1983) mathematical model in which the relationship can be calculated between angle ϕ and angle α with a friction force of 0 . This model has been validated by practical tests.
The results are in principal comparable with the data presented in figure 1-8.
In addition to the friction force recorded in the above-mentioned exercise, normal force Rz was also measured. The influence of angle ϕ and angle α on the magnitude of this is illustrated in figure 1-9.
A noteworthy result of this exercise was that the positioning of the ischial tuberosities in relation to the intersection of the seat and the backrest (135 mm and 170 mm respectively) had no effect on the magnitude of the friction force but did exert an little (0 - 5 %) influence on the size of the normal force Rz on the seat. The results are shown in figure 1-10. An explanation for this is not easily found, the positioning of the arms might have an influence on this.

The positioning of the ischial tuberosities on the seat determines the shape of the lumbar spinal column resulting from the sitting posture and partly influences the perception of comfort. This has already been discussed in section 1.3.3 .

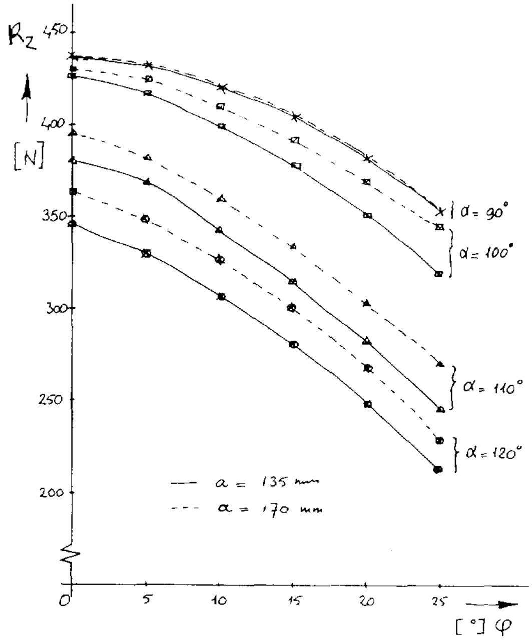


Figure 1-10 : The normal force Rz as a function of angle φ with angle α and distance a from the ischial tuberosities to the backrest as parameters for one female test subject of 60.5 kg and 1.72 m. (Staarink, 1978)

To summarise it can be stated that the sitting posture is to a great extent responsible for the *size* and the *direction* of the external load on the body and that, in relation to time, is one of the determining factors in the perception of comfort.

1.3.5 The stability of the upper part of the body

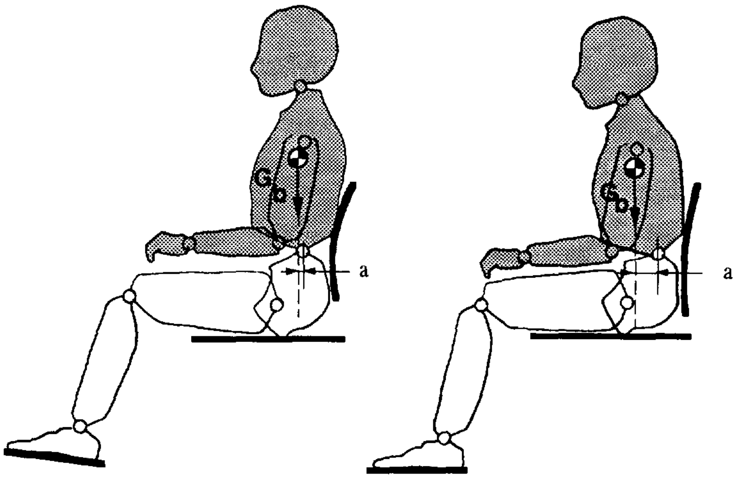
The level of stability in the upper part of the body determines the amount of energy which is required to maintain its posture. The amount of energy, in terms of time, is a determining factor in the perception of comfort. Depending on a back's individual characteristics the way in which this stability is brought about can be cumbersome to a greater or lesser extent on the spine.
The lumbar spinal column (LSC) has two main features which are of significance both for the physiological and the bio-mechanical aspects of sitting posture. These features differ per individual and are:

- the level of mobility and
- the shape of the lumbar spinal column.

The different kinds of lumbar spine an individual may have are:
- an extreme lordosis
- a normal lordosis
- flat
- a kyphosis.

A flat back and a kyphotic back are usually immobile. A mobile back can assume different shapes when the individual is seated depending on the type of support used (see section 1.3.3). The characteristics of the lumbar spinal column can influence the way in which the stability of the upper part of the body is or can be achieved.

The way in which the stability of the upper part of the body is attained is determined by the location of the centre of mass of the whole upper part of the body: head, trunk and arms in relation to the assumed lumbar pivot point. The centre of mass of the entire upper part of the body with the arms in the lap is roughly in the axillary region. For an active sitting posture the position of the pelvis or the form of the lumbar spinal column, both of which can influence each other, play a significant role, according to the model used, in the line of action of gravity in relation to the assumed lumbar 'pivot point'. Figure 1-11 illustrates this.
Drawing A in figure 1-11 shows the line of action of gravity running just in front of the lumbar 'pivot point'. This situation is reached when the mobile lumbar spinal column assumes a lordosis. In such a situation, with the presence of a pelvis support, negligible muscle exertion is required to attain active stability in the trunk. Non-active stability occurs by enlarging angle ϕ and angle α to such a degree that the said line of action runs along or behind the lumbar pivot. For a back with a normal lordosis this is when angle $(\phi + \alpha)$ is approximately 110°.
Drawing B shows the lumbar spinal column in kyphosis. A kyphosis may be a natural individual feature of the back but can also be attained in some situations, for example when an individual takes up a forward sitting position and the pelvis is tilted backwards. The resulting line of action of gravity for this posture runs in front of the lumbar spinal column. In this particular situation a moment Gb * a is exercised on the lumbar spinal column which must be countered by muscle power, unless the vertebrae have reached their furthest position in relation to each other. The consequence of this for pressure on the spinal vertebral discs is dealt with in section 1.3.3.



A: lordosis: distance a is small B: kyphosis: distance a is great

Figure 1-11 : The influence of the shape of the lumbar spinal column on the location of the centre of mass of the upper part of the body in relation to the assumed lumbar pivot point for an active sitting posture.

Whether or not an individual has consciously chosen to adopt an immobile kyphotic back described in the above scenario, a 'special' kind of stability is said to exist. Because the lumbar spinal column is immobile it cannot function as a pivot point for the stability of the upper part of the body. The pivot point is relocated to the ischial tuberosities. When the gravitational line of action runs behind the ischial tuberosities, as illustrated in figure 1-12, a non-active stability does indeed occur but this goes hand in hand nonetheless with a substantial moment of force Gb * a on the lumbar spinal column.

If over a long enough period of time this posture is maintained, the ligaments of the lumbar spinal column will be stretched under the influence of this moment, thereby advancing the state of the kyphosis to such a stage that it becomes irreversible.

A kyphosis of the lumbar back also has consequences for the position of the head in relation to the torso. Because the thoracal region of the torso tends to adopt a more forwards position in a kyphosis, the head, in order to adopt a line of sight focused on the horizon, will have to be raised somewhat further by increasing the neck extension. This condition is commonly found in the elderly population.

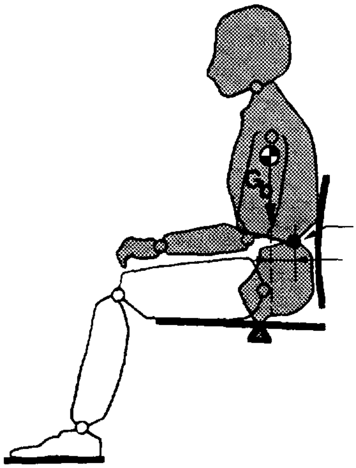
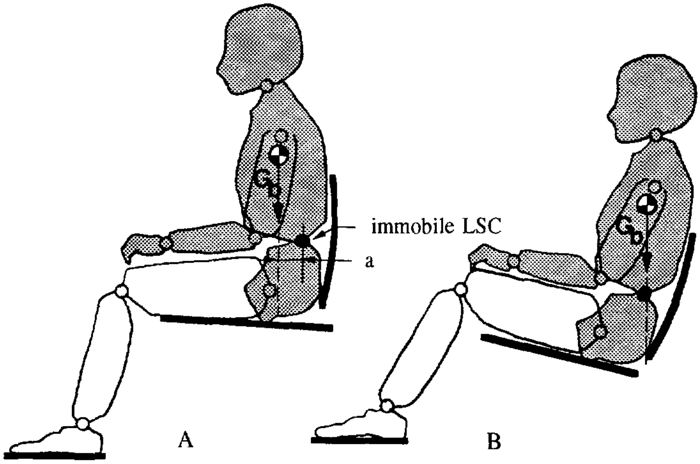


*Figure 1-12 : Stability of the upper part of the body with an immobile lumbar spinal column in relation to the tubera as pivot point and the introduction of a moment load Gb * a on the lumbar spinal column.*

A solution to this is to tilt the sitting posture by increasing the angle ($\phi + \alpha$) as illustrated in figure 1-13.
By tilting the sitting posture not only is then neck extension diminished but the moment of force on the lumbar spinal column is also eliminated. A non-active stability can of course be attained in this manner when the lumbar spinal column is mobile.

To summarise it can be said that the shape and mobility of the lumbar spinal column greatly influence the way in which an active or non-active stability of the upper part of the body is able to be achieved. By adjusting the angles ϕ, α and (α - λ), which define the specific lumbar support, an adequate stability in a seating support can be achieved in the upper part of the body. A sitting posture should aim to emulate the natural shape of the lumbar spinal column back in its standing position as much as possible. A moment load on the lumbar spinal column should be avoided in case of an immobile lumbar spinal column. A non-active trunk stability generally occurs when angle ($\phi + \alpha$) is roughly 110°.



A: kyphotic lumbar spinal column with compensatory neck extension
B: decrease of neckextension as a result of increase in angle ϕ

Figure 1-13 : The influence of sitting posture on the position of the head in relation to the torso for a kyphosis of the lumbar spinal column and on the elimination of the moment of force on the lumbar spinal column.

1.4 Influence of the seating support on the perception of comfort

The seating support, consisting of a seat and backrest, provides the basis for realising a sitting posture. The determining factor for the sitting posture are the angles ϕ and α. The sitting posture is responsible for the magnitude and the direction of the reaction forces of the seat on the buttocks (and not the seat itself!). The seat is however responsible for the way in which the reaction forces are distributed on the buttocks and for the micro-climate which occurs between the seat and the skin; in other words, for the quality of the moisture and heat regulation. The time factor appears to be greatly influential on these phenomena.
The seat also reacts to the dynamics of sitting. This feature is referred to the sitting stability of the cushion and is regarded as being a very important element in determining comfort.
The following sections will analyze these phenomena from a perception of comfort standpoint.

1.4.1 Pressure-distribution

Cushions can be perceived as being hard or soft. A cushion which is seen at first as being soft may, in the course of time, be perceived as hard. A hard and uncomfortable cushion may be perceived by someone else as being satisfactory and comfortable. Comfort is something which therefore appears to be individual and time-related. The human buttocks also appear to possess a number of individual traits, e.g in shape, structure constituting tissues and bones and volume.
Perception of comfort is related to the degree to which the reaction forces of the seat have on the posterior and the way in which the seat transfers these forces to the posterior.

The weight of the upper part of the body is conveyed via the lumbar spinal to the pelvis and transferred to the seating plane via the softer parts of the buttocks.
The sitting weight comprises about 75% of total body weight when a person is sitting upright with the arms in the lap. The size of this sitting weight is partly dependent on the angle ($\phi + \alpha$).
The seat responds to the sitting weight by means of reaction forces. The load on the posterior appears not to be distributed evenly. Figure 1-14 gives an impression of the general distribution and size of the reaction forces on the posterior recorded from measurements taken between the posterior and the seat. This is the so-called *interface pressure.*

The way in which the reaction forces are distributed across the seating plane and the resulting interface pressure are characteristic and are a feature of all studies. The highest pressure is always found on bone protrusions i.e. under the ischial tuberosities.
The quality of 'pressure-distribution' which a seat posesses are, in this context, understood to exist when the distribution of reaction forces of a hard even seat show a pattern of pressure contours around the ischial tuberosities, the pressure decreasing outwards. A seat with good pressure-distribution qualities will 'attempt' to keep pressure levels on the ischial tuberosities a low as possible. This can be done by using the area around the ischail tuberosities to maximum effect in load absorption by making the loaded surface as extensive as possible. This is a function of the seat features. The load and therefore the pressures are distributed across the posterior.

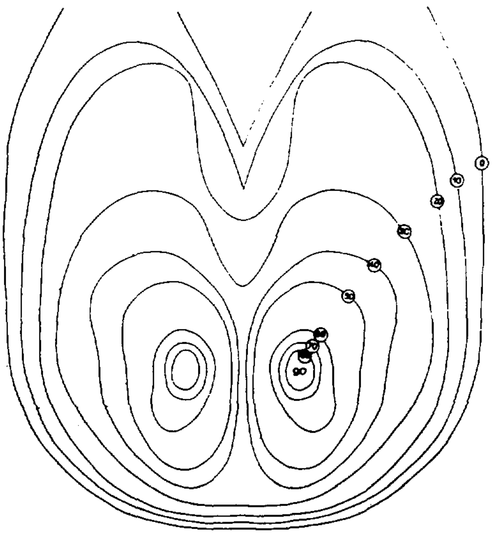


Figure 1-14 : The distribution of interface pressure (gr/cm²) on the posterior (Rebiffé 1969).

Cushions are perceived as being comfortable when for example the pressure under the ischial tuberosities is relatively low and the range in pressure - the so-called pressure gradient - small.

Maximum pressure under the ischial tuberosities also appears to be related to individual characteristics.

Individual characteristics include:
- the sitting weight of the individual;
  the sitting posture determines in turn the percentage of sitting weight applied as load on the seating plane.
- the amount of soft tissue;
  the larger the mass of soft tissue present, the lower the recorded maximum pressure under the ischial tuberosities (Chung 1988)
- the position of the pelvis, in the sagittal as well as the frontal plane;
- muscle tension in the buttock;
- the shape of the ischial tuberosities;
  asymmetry, bone excrescence, and a non-smooth surface will lead to pressure increase;
- posture anomalies which lead to asymmetry.

The characteristics of the seating support are formed by a combination of the materials from which and the way it has been constructed.
The construction which displaces the forces to the frame of the chair is called the 'support structure' of the cushion. This can be made up of:

- a rigid support comprising:
  - a flat surface or,
  - a pre-formed shell;
- an adaptable support comprising:
  - a rigid narrow outer frame inside which an adaptable structure is fitted; this may be:
  - resilient due to the presence of elastic webbing or no-sag springs or ;
  - non-resilient, e.g. a 'sling' (hung from two sides) or 'trampoline' system (hung from four corners).

If the surface of the support structure is provided with a 'pressure-distributing' medium, with or without a cover, we call it a cushion. In everyday terms a cushion is generally interpreted as being this 'pressure-distributing' medium plus a covering. The support structure also plays a major role in determining the definitive pressure-distribution qualities of the cushion and in this context it should be seen as an essential to the cushion's functioning. From here on, when we refer to a cushion in the text, we mean the following:
the cushion **plus** the support structure.

Cushion features which influence the effects of pressure-distribution include:

- the shape of the support structure when subjected to a load;
- the support structure's construction;
- the characteristics of the pressure-distributing medium used and the way it is applied;
- the characteristics of the cover.

Section 2.3, 'The causes of decubitus', makes a bio-mechanical analysis of the way in which the external load is transmitted onto and into the posterior and what we can conclude from this as to the right method of support, i.e. load. In chapter 3 an analysis will be made of the way in which pressure-distribution is effectuated using a cushion, by recourse to results from a number of simple experiments using foam as a pressure-distributing medium. The results of these analyses will be extrapolated for other pressure-distribution systems.

To conclude this section the individual character of pressure-distribution is shown in figure 1-15 where the results are shown of measurements taken of various test subjects in respect of the maximum interface pressure of one cushion. The individual variations appear to quite extensive.

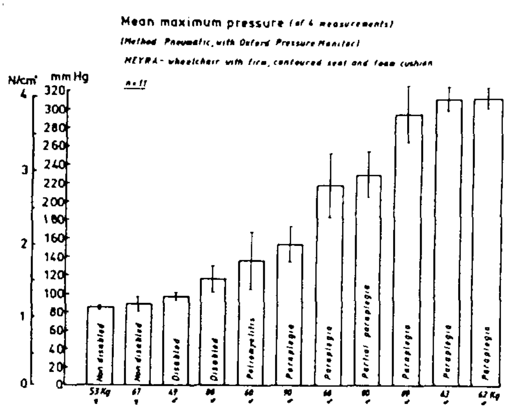


Figure 1-15 : Average maximum interface pressure of a cushion for test subjects with and without a motoric disorder and differing body weights (Engel 1986).

1.4.2 Moisture and heat regulation.

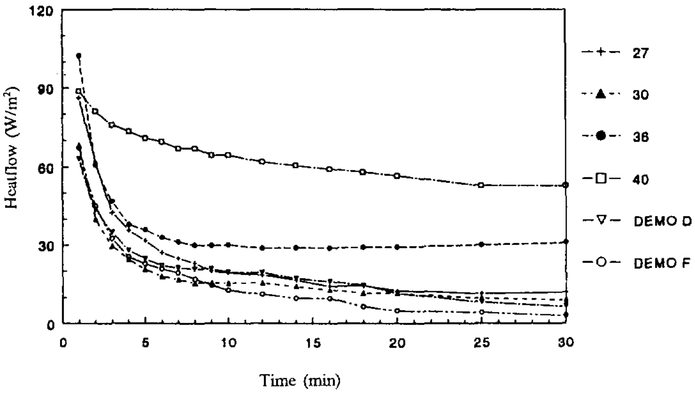
For long periods of sitting moisture and heat are, in addition to pressure-distribution, important factors influencing the perception of comfort. Mainly as a result of muscle activities an individual generates a certain amount of heat depending on the air temperature and the individual's movements. Where there is a difference in temperature between the skin and the immediate surroundings there arises a dry heatflow from the individual to the surroundings. The level of this outflow depends on the difference in temperature between the skin and the surroundings and the heat insulation of the layers between the skin and the surroundings. This current of heat is also influenced by ventilation and the flow of air over the body.

Human beings are capable of varying the level of skin temperature within set limits allowing them to some degree to adapt to this heatflow. Furthermore a certain amount of moisture will always pass through the skin. This usually evaporates and, if permitted, passes through the layers of clothing or otherwise from the skin to the surroundings. The evaporation energy is extracted from the skin thus causing a heatflow. The amount of moisture passing through the skin may increase, thereby producing an extra heatflow. If the amount of moisture passing through the skin exceeds normal levels or cannot be dissipated quickly enough, moisture forms sweat on the skin. This occurs for example when the water-vapour permeability of the layers between the skin and the surroundings is too small. Sometimes moisture is absorbed by one or more of the layers between the skin and the surroundings, thereby keeping the skin dry. It is only a matter of time, however, before the layers become fully

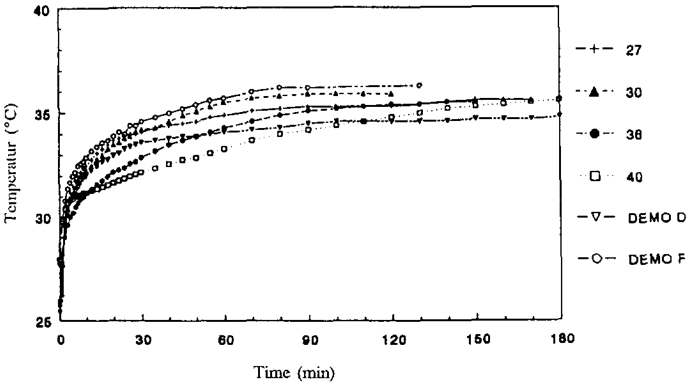
permeated with moisture (Engelbert 1992).
In the case of seating supports this means that an excessive heat insulation of the seat causes a dry heatflow which is too small. The body compensates for this by generating more moisture which must evaporate through the seat or be dissipated otherwise. If this does not take place, liquid moisture will form in the seat or in the space between the skin and the seat.

Figure 1-16 shows the results of measurements performed on one individual relating to the heatflow, the temperature in the anal cleft, and the relative humidity using different types of cushions. These tests were carried out in a climatic room at a temperature of 25° and a relative humidity of 50% with a test subject measuring 1.83 m and weighing 112 kg (Engelbert 1992).
For the duration of the test the subject wore a tight-fitting, elasticated pair of tights through which moisture could pass. The temperature and the relative humidity were measured using a round sensor (type Vaisala HMP 123-B) placed in the anal cleft. Two TNO heatflow meters (type WS 22 HT) were placed under each buttock. The tests were carried out using six different cushions each possessing the following properties:

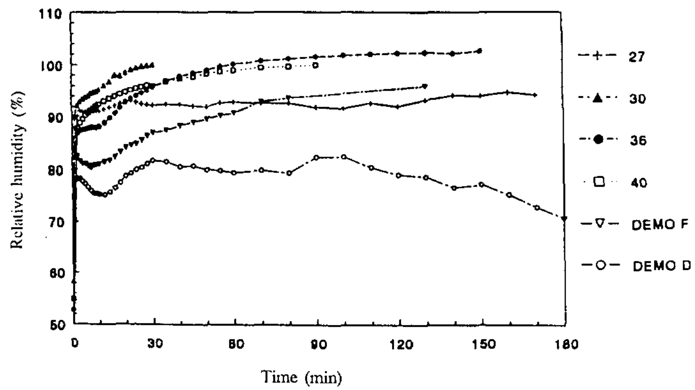
Cushion 27	
cover	:woven fabric
pressure-distributing medium	:latex foam rubber
support structure	:wooden frame with webbing
Cushion 30	
cover	:woven synthetic fabric
pressure-distributing medium	:polyether
support structure	:sling
Cushion 36	
cover	:rubber
pressure-distributing medium	:one cell air-filled cushion with some openings
support structure	:sling
Cushion 40	
cover	:knitted cotton
pressure-distributing medium	:solid gel
support structure	:sling
Demo D	
cover	:woven woollen fabric
pressure-distributing medium	:horsehair + latex ('coconut hair')
support structure	:adaptable open structure ('trampoline')
Demo F	
cover	:synthetic stretch fabric
pressure-distributing medium	:100 mm Draka 9018 foam
support structure	:flat surface



A: Heatflow cushions



B: temperature of test subject in anal cleft



C: relative humidity of test subject in the anal cleft

Figure 1-16 : Results of moisture and heat regulation for test subject using different types of cushions.

The results can be summarised as follows:
- After 10 minutes of sitting the temperature of all cushions was between 31°C and 33° C.
- After 80 minutes the temperature was recorded at between 34°C and 36° C.

The temperature for all the cushions remained constant except for the gel cushion (40) whose temperature steadily rose to 35.5° after 2 hours.

The cushion with the best moisture regulation (Demo D) showed the lowest temperature: 34.5°C after 2 hours. The two cushions with the next best moisture regulation were cushion 27 and the gel cushion at 35.5°C.

The relative humidity is regulated after about 40 minutes:
- three of the cushions had then reached a maximum of 100%,
- Demo D cushion, filled with vulcanised hair, reached 81% remaining at around this level for some time; two other cushions with moisture regulating properties, cushion 27 and Demo F, fluctuate around 93%. After 3 hours Demo D cushion falls to 70%.

Evidently the moisture regulating properties inherent to the Demo D cushion not only facilitate dissipation of moisture but also of much heat. The effect of this is to produce the lowest temperature after 2 hours sitting. As can be seen, a good moisture regulation pays double dividends!

The results of these tests are comparable with the results of similar tests which have previously been carried out (Fisher 1978, Stewart 1980, Faust 1984).

1.4.3 Sitting stability

The sitting stability of a cushion is an extremely important factor in determining the perception of comfort. A cushion with sitting stability enables the upper half of the pelvis to remain in a roughly horizontal position when making a sidewards movement. The effect of this is that the head - an important input centre - remains stable, facilitating awareness of the surroundings. In this context a sitting support should not only be seen as a means by which a suitable sitting posture for a specific activity can be realised, but also as a 'platform' from which forces can be discharged in order to enable actions. The stability of this 'platform' increases the certainty as well as the accuracy of actions, in turn decreasing the exertion which is necessary to carry these out.
In this respect the height adjustable office chair which rotates around a central axis requires separate treatment since this construction causes a degree of

*in*stability. It is clear that because of the rotating properties of the chair it,s seat cannot function effectively as a 'platform'. The reaction forces of the feet and arms need to be transmitted via the central column and are subsequently required to be in balance with each other since the seat, because of its fixed rotating axis cannot supply a moment for the reaction forces. In practice this means that when the upper part of the body is supported on one side, the reaction forces are not transmitted via the central axis, meaning that the torsion moment is provided by the lumbar spinal column. Because the reaction forces constantly vary during actions, constant correction is required. This is not only laborious for the spinal column, but also for the orientation of the head in space. The effects on the body of the chair as a stable or instable 'platform' have not yet been given due consideration in previous studies. It is very plausible that the instability in question is the cause of many physical disorders which are ascribed to an incorrect sitting posture.

1.5 Summary and conclusions

A sitting posture is determined by the position of bodily segments in relation to each other and the position as a whole in space. The position of the upper part of the body in relation to the thighs - angle α - and the position of the thighs in relation to the horizontal plane - angle ϕ - are characteristic features of the sitting posture.

Individuals appear to adapt their sitting posture to the activity which they wish to carry out. In this respect a specific relationship always appears to exist between the size of angle α and the size of angle ϕ. This relationship can be defined with the aid of physiology and bio-mechanics.
Analysis of the reaction forces of the supporting element on the body shows that a correct combination of angle ϕ and angle α helps eliminate friction forces as well as reaction forces of the supporting element on the body.
This is perceived as being comfortable and individuals will intuitively adopt this posture.
The suitability of a sitting posture for a specific activity is determined by the level of eye-hand co-ordination required and by the energy necessary or available to maintain the posture.
In this respect the perception of comfort is also determined by the position of the joints. In general these have a comfortable perceived 'central' position which is determined by the length of the muscles on either side of the joint.
Where eye-hand co-ordination is necessary the relaxed line of sight determines the sitting posture. Because of the line of sight which is required the posture is inevitably 'active', i.e. the stability of the upper part of the body must be maintained by muscle exertion.

In situations where no eye-hand co-ordination is required the individual will adopt a sitting posture which needs as little energy as possible to maintain. The location of the centre of mass of the whole of the upper body in relation to the assumed lumbar pivot point is also seen to be a determining factor. An immobile lumbar back which is either flat or in kyphosis has a assumed pivot point under the ischial tuberosities. This can produce undesirable 'stability' due to the introduction of a moment load on the lumbar spinal column. This moment can lead to more advanced states of kyphosis in the lumbar spinal column.

Time is also a factor in the perception of comfort. The body is not made for static load and is both in physiological and neurophysiological terms dependent on movement. This 'motility' provides variation of load. Movement is also necessary in order to experience sensation, intentionally or otherwise, and vice versa. In neurophysiological terms the position of the head in space in, when the gaze is directed towards the horizon, can be seen as the referential posture for all actions. This position maximises the body's ability to carry out the most accurate of movements since this has been learned from an early age onwards and programmed into our brains.

The pressure-distribution qualities of supporting elements play an important role in the way in which reaction forces are transmitted onto the seating plane. The properties of the support structure are also an important factor in this. The purpose of pressure-distribution is to minimise load on the area around the ischial tuberosities, thus influencing the perception of comfort.
The equalisation of the pressure-distribution is also an important element in increasing comfort.
A seating support not only provides the individual with the opportunity to adopt a sitting posture but also affords a 'platform' from which to carry out activities. A stable 'platform' is essential for accurate eye-hand co-ordination. A non-stable 'platform' can lead to fatigue and back pain. The position of the head always needs to be corrected when the upper part of the body changes position. The position of the upper and lower parts of the trunk in relation to each other is also constantly subject to corrections, in particular in the lumbar region. For long periods of sitting a good moisture and heat regulation promote comfort. A good moisture regulation likewise effectuates a good heat regulation, since heat disappears with moisture.

2.0 Sitting in a wheelchair

Generally speaking the 'principles' of sitting discussed in chapter one are equally applicable to sitting in a wheelchair. After all there is no reason to suspect that the bio-mechanical and (neuro)physiological aspects of sitting should be fundamentally different for individuals who are compelled to perform activities from a sitting position on account of their functional impairments. Where they do appear to differ is in the in-and-outs of these principles. There are two aspects which make sitting in a wheelchair different: the physical condition of the user and the fact that it is an enforced and therefore a prolonged activity.

Enforced sitting means that day-to-day tasks normally performed in a standing position must be carried out from the wheelchair. This places demands on the wheelchair-user, on the wheelchair and on the user environment.

The time factor must also form part of the equation with respect to enforced sitting. We cannot get away from this fact. It means that a great deal of attention must be paid to counteracting the static character of load, in other words to the essential dynamics of sitting. Sitting posture, sitting behaviour and sitting conditions need to be optimised in order to compensate for the negative effects of enforced sitting. The properties of the cushion play an important part in preventing pressure sores, or decubitus, certainly in situations where, as result of a clinical condition, sitting comfort cannot be perceived by the individual. Decubitus should at all times be avoided.

Wheelchair-users are special in a number of ways: they cannot walk and often cannot stand up. This can be the consequence of an illness, an accident or is congenital. Other functions, in addition to walking, may be affected, e.g. the arms, the hands, the trunk muscles, the workings of the joints and neurophysiological functions relating to perception.
These additional impairments not only influence the sitting posture but will, of course, affect the way in which tasks are performed. The possibilities which sitting posture offer can be used to minimise or eliminate the effects of an impairment and to prevent a deterioration in physical condition. This places demands on (the behaviour of) the wheelchair-user as well as the wheelchair-user.

2.1 Characteristics of wheelchair-users

Physical impairments can be divided into three major categories each of which exerts its own specific influence on the choice of sitting posture:

- a disorder of the muscle functions;
- a disorder of the functions of the joints;
- abnormal anthropometry.

Taking these three categories as a basis, it is possible to describe the relevant aspects of wheelchair sitting for all clinical conditions.

The pathology of muscles can be described on the basis of four features (Muller and Staarink 1974):

- the location of the disorder;
- reduced strength;
- reduced endurance;
- reduced co-ordination.

As far as the first three features are concerned it is particularly important in the context of sitting posture to know whether the disorder is:
a) *symmetric* or,
b) *a-symmetric* (i.e. more or only on one side)
Symmetric disorders - those affecting both sides - might be localised, e.g. as a result of a spinal cord lesion, or affect the whole body, e.g. multiple sclerosis.

The pathology of joints can be defined by two features:

- restriction in movement
- a fixation

Restriction in movement can be caused either by a 'mechanical' limitation or the sensation of pain during movement.
In the case of irreversible injuries to the knee and hip joints, fixation, resulting from an operation, also occurs mainly on one side only.
A special form of fixation, which has an important bearing on sitting posture, is the fixation of the spinal column.

The lumbar spinal column shows two characteristics which are important in respect to the physiological and bio-mechanical aspects of sitting posture.
These are:

- mobility, and
- the shape of the lumbar spinal column.

These features have already been discussed in section 1.3.5. The only addition to make here is that of scoliosis, a deviation of the spinal column in the transversal plane.

The cause of these features can be either a direct or an indirect result of the disease.
Enforced sitting resulting from the loss of the leg function can have many undesirable side effects: oedema (an accumulation of fluid in the leg caused by sustained muscle contraction as a result of insufficient exercise), contractures, subsequent posture abnormalities and decubitus can all be considered under this category.

The choice of sitting posture and, with it, the 'programming' of sitting behaviour, aim to compensate for disorders and facilitate activities without the occurrence of side effects.

2.1.1 Characteristics of users of wheelchair-cushions.

According to workers in the field the most commonly quoted characteristics of wheelchair-cushion users are those associated with an increased risk of decubitus. Many techniques exist to measure the risk of decubitus. In the Netherlands there is a so-called 'consensus group' which has published a brochure on the subject of decubitus prevention and treatment (Haalboom 1992).
Characteristics of wheelchair-users have been identified on the basis of cushion characteristics. In selecting these characteristics a distinction can be made between those characteristics associated with features of sitting and those characteristics which are associated with cushion design (e.g. those taking into account transpiration and incontinence).

Characteristics of cushion users are:
- the degree of sensitivity to decubitus;
- the presence or absence of sensibility;
- the ability to modify posture or lift;
- a normal or excessive level of transpiration;
- the level of inconvenience from incontinence;
- the symmetry or asymmetry of the pelvis.

These characteristics are defined in more detail below:
- Sensitivity to decubitus in the buttocks:
  Factors which play a role in sensitivity to decubitus include degeneration of the gluteus muscle by a process of atrophy, defective vascular refill or defective vascularization which influence blood circulation, and excessive bodyweight in relation to the seating surface.

- Sensibility:
  The perception or not of stimuli which result from load as a result of sitting. Excessive load is usually registered by the body and signals sent to the brain. The brain reacts by issuing stimuli which lead to a change in sitting position and therefore a change in the load. This mechanism protects the body against prolonged localised load.
- Changing position:
  The possibility to change the position of the buttocks in relation to the seat. These changes in position result in a change of load, usually a localised reduction. A change in position can be brought about by a so-called lifting action by which the load on the seating surface is relieved by pushing the body upwards using the arms on the armrests. It can also be achieved by periodically changing sitting posture, e.g. by changing to a posture specific to the task being carried out or by movements resulting from spasticity.
- Excessive transpiration:
  A level of moisture discharge during sitting which places special requirements on the moisture regulating capacity of the cushion. The influence of moisture on the development of decubitus is thought to be considerable. This is discussed further in section 2.3.2.
- Incontinence:
  A level of incontinence which places special requirements on the cushion. We are concerned here mainly with loss of urine which cannot be otherwise absorbed by incontinence pads.
- Asymmetric sitting posture:
  A level of asymmetry in respect of the pelvis and/or thighs in the medial plane which places special requirements on the cushion.
  This feature is extremely important for a small group of users. In the present study no test methods have yet been developed to measure cushion attributes in relation to this feature.

In theory a large number of user groups for cushions can be identified on the basis of these various user characteristics. After consultation with a number of individuals working in the field, a total of 10 user groups were initially identified and the viability of this distinction was assessed (Staarink 1990). This assessment eventually narrowed the selection down to three user groups and three kinds of use.
The following user groups can be distinguished:

Group 1:
- able to modify position,
- not sensitive to decubitus, and
- sensible.

A cushion for this type of user can be defined as a "low-risk user cushion" (LRUC).

Group 2:
- able to modify position,
- sensitive to decubitus, and
- sensible or non-sensible.

A cushion for this type of user can be defined as a "medium-risk user cushion" (MRUC).

Group 3:
- not able to modify position,
- sensitive to decubitus, and
- sensible or non-sensible.

  A cushion for this type of user can be defined as an "high-risk user cushion" (HRUC), since users in this group are sensitive to decubitus and cannot modify their position.

Some explanation is required as to how the categorisation was arrived at:
No differentiation is made in Group 2 and 3 in respect to sensibility. They can lift as well as understand that they must lift. An intact sensibility might well stimulate lifting further but training for groups with a non-intact sensibility is focused on continuous movement and the result is therefore the same.
Group 3 users are not able to modify their position or lift. An intact sensibility can provide reason enough for the individual to request assistance in modifying position when a measure of discomfort is perceived. This will usually happen during or immediately after the process of sitting down. For this reason the group carries a risk which, relatively speaking, is somewhat smaller. The prolonged nature of sitting without movement (or lifting) however makes this group extremely susceptible and comparable to the group with a non-intact sensitivity.

With regard to cushion construction, a distinction is made between moisture regulation and moisture control. The following three kinds of use can be differentiated:
- normal use:
  where no excessive transpiration or unacceptable incontinence is present;
- use in situations where excessive transpiration is present;
- use in situations where non-manageable incontinence is present.

When we cross-reference the three user groups with the three types of use, the following table is produced:

	normal	transpiration	incontinence
LRUC	x		
MRUC	x	x	(x) ↓
HRUC	(x) →	x	x

Table 2-1 : Selection of user groups and type of wheelchair-cushions.

Since 'excessive transpiration' and 'unacceptable incontinence' are 'decubitus-sensitive' factors, two of the possible combinations have been left empty.

The crosses set in parentheses require some further explanation.
an HRU cushion for normal use might sometimes be required to possess moisture-regulating qualities at 'transpiration' level, as the individual is not able to modify position.
An MRU cushion, suitable for unacceptable levels of incontinence needs to have sitting attributes which correspond to that of an HRU cushion on account of extra susceptibility.

The categorisation of 3 user groups and three types of use eventually leads us to the conclusion that there are five different cushions:

- a low-risk user cushion for normal use
- a medium-risk cushion for normal use
- a medium-risk cushion for use in situations of excessive transpiration
- a high-risk cushion for normal use and excessive transpiration;
- a high-risk cushion for use in situations of non-manageable incontinence.

2.2 Therapeutic and curative aspects of sitting posture

When the functioning of the legs has been reduced to such a level that walking is barely or no longer possible, a wheelchair is employed to facilitate mobility. This also means that all tasks will have to be performed from a sitting position in the wheelchair.

A random selection of daily activities might reveal the following list of tasks:
- transfer from bed to wheelchair and vice versa
- getting around
- toileting

- eating at the table
- conversation
- working at the table
- transfer from wheelchair to toilet and vice versa
- watching TV
- reading
- resting

Every task requires its own specific sitting posture. The tasks listed above can be clustered and characterised in the same way as in section 1.2:
- a sitting posture required to make a transfer,
- an active sitting posture with an active stability of the trunk,
- a semi-active sitting posture with a non-active stability of the trunk,
- a passive sitting posture with an active positioning of the head,
- a relaxed posture with non-active positioning of the head.

In sequence, these sitting postures can be characterised by the following aspects:
- increased stability of the sitting posture,
- decreased muscle activity necessary to maintain the posture,
- increased relaxation,
- the decreased likelihood of activities which require eye-hand co-ordination,
- an increased orientation of sight towards the horizon (up to the inactive posture),
- decreased load on the buttocks and the spinal column,
- an increased necessity for support of the head.

The therapeutic selection of sitting posture and the accompanying 'programming' of the sitting behaviour aim to compensate for limitations and facilitate activities without causing any side effects.

Adapting one's sitting posture to a particular task enables the essential dynamics in and on the body which have a preventative influence on the effects of enforced sitting.
These negative effects can be summarised as follows:
- too little movement; this will result in increased scarcity of afferent stimuli to the brain, leading in turn to fatigue and reduced performance levels (Schoberth 1978);
- lasting posture abnormalities which result from lack of posture control and too little movement;
- the development of decubitus as a result of placing an excessively high and/or incorrect load on the buttocks over a prolonged period.

The therapist's approach is to explore the possibilities of sitting postures in

compensating for the impairments or disability.
This sometimes means intervening in the ideal relationship between 'sitting posture' and 'task', when this is not altogether possible given the disability. This is particularly true in cases where an active stability in the upper half of the body cannot be achieved. Section 1.3.4. lists possibilities of how sitting posture may facilitate a satisfactory level of stability in the trunk. One should be cautious however of undesirable forms of stability which may be induced in situations where an immobile lumbar spinal column is present, as discussed in section 1.4.3.

Changes in posture and the ability or inability to adopt an active sitting posture are crucial factors in preventing many of the undesirable side effects which enforced sitting poses.

In addition to the above-mentioned functional and preventative aims, the sitting posture and sitting behaviour can also be used to realise therapeutic and curative objectives. By *positive* stimulation and by encouraging the deployment of 'examples of correct and desirable postures' a learning process can be set in motion which is based on the so-called 'senso-motoric reafference principle': postures are registered sensorially and transmitted to the brain; conversely muscle movements are controlled by the brain on the basis of acquired patterns of movement. The permanent feedback emanating from the action- reaction mechanism not only produces a balance which results in a posture but also activates a learning process.
This principle applies to normal sitting behaviour and even more so to the sitting behaviour of wheelchair-users since it produces both preventative and curative effects.
The notion behind this is that the brain requires as much acquired input as possible - thus the same input - in order either to enable old action-reaction patterns, to help re-stimulate these or to prevent pathological patterns which occur as a result of an incorrect input.
This approach implies that the choice and 'fine-tuning' of the sitting posture, and the 'programming' of sitting postures are of extra importance to individuals with an impairment or disability on account of the size and direction of the external load.
In neuro-physiological terms a balance of reaction forces in a sitting posture where friction forces are absent is crucial, since incorrect postures where friction forces are present cannot as such be recognised by the brain in the case of wheelchair-users with impaired sensibility. This has the effect of sending the wrong (programming) instructions to the brain. This mechanism is described in section 1.3.1.
In this manner patterns of movement lost as a result of brain damage can be re-acquired since other brain tissue is able to take over this function. This principle can be applied curatively, especially in cases of hemiplegia.

Sitting postures are also capable of inhibiting spasms. Spasms are sudden, uncontrolled and acute contractions of the muscles.
Specific sitting postures or movements appear to have a bearing on the reduction of spasticity. These are known as reflex inhibitive postures and reflex inhibitive movements (Tournier 1988). These postures exert a 'positive' influence not only on the proprioceptive input transmitted from the muscles to the spinal cord, but also on the exteroceptive input from the skin sensors. A permanent and low level of external pressure results in general in a tone reduction, whereas friction on the skin almost always results in an increase in tone.
Keypoints of control in programming these postures and movements are those points on the body from which the posture reflex activity can be influenced therapeutically. The most prominent are the following:

- the head/neck region: the position of the head in space,
- the lumbo-sacral transitional region: the level of lumbar lordosis,
- the pelvis/thigh angle,
- the palm of the hands/flexion of the wrist,
- the soles of the feet/flexion of the ankle.

Permanent pressure on the palms of the hand and soles of the feet usually results in a reduction in the extension tone of the upper and lower extremities respectively.
The sequence in which the bodily parts are positioned when a sitting posture is adopted is, in this case, very important. The initial stages are always characterised by the correct orientation of the head with the gaze in line with the horizon. The manner and degree of influence exerted by the keypoints of control are specific to the individual and require a lot of experience.
Spastic patients must acquire a feel for normal muscle tone and movements since otherwise they do not know how to move, unless this has been taught to them by the therapist. This can be achieved by acting out the movements in a wheelchair and by repeating these to reinforce this. They need to follow a new learning process in which the consequences of spasticity are taken into account. This 'positive' stimulation of the sensors can be brought about by a programme of movements. They must learn to make these movements by themselves without resorting to abnormal tonic reflexes for arbitrary tasks. These are the so-called 'reinforcement principles'.

Reduction of spasticity facilitates a starting point from which selective movements might be made.
More reflex inhibitive postures might need to be sought out, either by the individual himself or with the help of the therapist. These movements are essential since spasticity increases when there is a lack of movement.

The conclusion to this section is that general mechanisms which are based on

'normal' sitting postures should be encouraged for people who have been forced to adopt permanent sitting behaviour as a result of an impairment or disability.
On the whole this implies that wheelchair-users have to be able to adopt a number of correct sitting postures, ideally by using their own initiative and expertise. Correct sitting postures can be defined as postures where shear forces as well as reaction forces of the support elements are not required to achieve a balance of reaction forces

2.3 What causes decubitus?

Decubitus forms as a result of *continuous* distortion of tissue. This causes physiological and/or mechanical damage to cells.

The 'physiological' cause is brought about by poor nutrition of cells over a long period of time, resulting from the poor levels of supply and discharge of nutrition and waste products respectively. This manifests itself in the form of ischaemia, the localised deficiency of blood flow leading to paleness of the skin. The cause of this is compression of blood vessels and lymphatics under the influence of a load. Blood pressure in the capillaries has normal values of between 20 - 35 mmHg. An internal pressure of more than 35 mmHg resulting from an external load squeezes fluid out of these vessels and closes them off.

The 'physiological' scenario described above can be reinforced by additional risk factors such as:
- defective vessels as a result of vascular disease;
- insufficient O_2 uptake as a result of lung disease;
- a shortage or lack of specific nutrients, iron, vitamin and protein,wich is common in patients with a spinal cord lesion.

Bar (1998) has given a fairly detailed synopsis of research results in the field of metabolics, as too has Crawshaw (1989).

The 'mechanical' cause of tissue degeneration can be explained as follows: Interstitial fluid which is located between cells, acting under the influence of pressure differences, is squeezed out causing changes in volume within the tissue. At the point of contact between these differences in volume shear forces occur which, because of the lack of interstitial fluid, operate directly on the cell walls causing damage. The amount of damage in combination with the quality of the metabolics will determine whether decubitus results or not (Reddy, 1981).

Interstitial fluid also plays a role in respect to the metabolics. The one-way discharge of fluid will exert a negative influence on the metabolics and will reduce the capacity of the tissue to recuperate locally.

A relationship between the size of the external pressure and the permissable time limit of the load can be found in literature on the subject. Reswick and Rogers (1976) clinically remodelled the relationship between pressure and time, which Koziak (1961) calculated using a dog, for humans. Figure 2-1 shows these results. The pressure relates to the interface pressure measured between the skin and the seat.

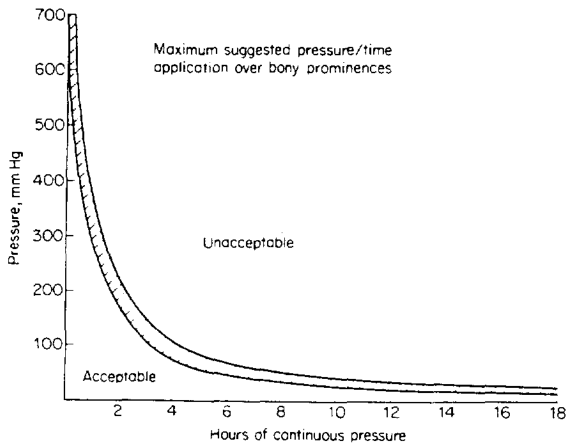


Figure 2-1 : The acceptable relationship between the amount of interface pressure and time duration according to Reswick and Rogers (1976).

Unacceptable levels of pressure and time are often linked with the amount of assumed capillary pressure of 25 - 35 mmHg and the amount of external pressure necessary to block the vessels. This explanation doesn't however appear to go far enough. After all, the pressure measured in the context of the graph is the so-called interface pressure, measured *between* the seating surface and the seating support. Internal pressure, however, can attain values which are two to three times as high as this. Even cushions which have optimum pressure-distribution qualities cause a much higher pressure on the ischial tuberosities directly than the capillary pressure. The lowest *internal* pressure recorded on the ischial tuberosities, in the cushion tests results carried out in the framework of this study, amounts to 90 mmHg. Given this fact plus the level of capillary pressure experienced it is astonishing that so few people suffer from decubitus. Certain mechanisms must therefore exist which act in a positive way to preserve the tissue.

One explanation might be that Reswick and Rogers' pressure/time correlation is partly based on small fluctuations in load which will be always present in practice and that these have a positive influence on the nutritional situation in the cells. It is plausible, within the acceptable level of the graph where the interface pressure is much more than 35 mmHg, that a constant variation in load and, with it, internal pressure, will result in pumping actions in the capillary vessels, thus facilitating the transport of fluids and metabolism. A pre-condition for this, however, is that the vessels do not block up as a result of distortion due to external and/or internal shear forces. The question remains whether the pumping action, that we have assumed is generated, produces enough pressure to force open the distorted and blocked vessels.

Reddy (1981) links Reswick and Rogers' graph with the relationship which exists between the level of local pressure differences and the level of interstitial fluid flow. Substantial pressure differences will quickly squeeze out interstitial fluid; small pressure differences have the same effect albeit over a longer period of time. Whereas with large pressure differences the chance of acute mechanical damage will be substantial due to the load which acts directly on the cell walls, with a small pressure difference the combination of more limited damage and a prolonged shortage of metabolics will achieve the same results.

Reddy's analysis of one-way interstitial moisture flows can perhaps be applied to the occurrence of distortion. Distortion which results from a combination of pressure and shear forces might be more effective in squeezing out the interstitial fluid than differences in pressure alone. The comparison with squeezing out a sponge springs to mind here. Distortion reduces the interstitial space forcing the fluid out whereby the load - in this case the shear forces - are transmitted directly onto the cell walls. This can cause mechanical damage to the cell.

Most literature (Crenshaw 1989) considers the combination of pressure and shear forces as the most potent factor in causing decubitus.

In addition to the level and nature of the load there are a number of risk factors which are either human-related or determined by external circumstances and have a negative bearing on the formation of decubitus. A number of characteristics relating to users and usage have already been specified in section 2.1.1. in which the selection of user groups by type of wheelchair-cushion was discussed. Section 2.3.3. will discuss these in more detail in addition to a number of other risk factors which are present.

2.3.1 Analysis of internal load

The external load on the buttocks is formed by the reaction forces of the seat. The size and direction of these reaction forces are determined by the sitting posture. The distribution of these forces across the buttocks is determined by the characteristics of the support element.
The human posterior consists of the pelvis which is surrounded by soft tissue and sealed by skin. This soft tissue consists of a non-homogeneous and non-isotropic material with visco-elastic behaviour, due to the interstitial fluid, which can be squeezed out. Furthermore the distance between skin and bone differs from place to place. Nowadays finite element methods are applied which attempt to gain an insight in the complex issue of pressure distribution within the buttocks.
In this section a simplified approach has been taken, mainly based on solid material mechanics, in an attempt to show what might be happening inside the soft tissue when different ways of loading are applied.

The absence of friction forces in the form of reaction force of the seat on the buttocks does not mean that there might be no shear forces internally.
In figure 2-2, which includes a cross-section of the pelvis, load is represented by a single normal force: F. This force is transmitted to the pelvis, which responds with reaction force R_F. R_F can be resolved in R_Fn, a perpendicular force on the pelvis, and R_Fs, a force in the pelvis plane. The 'normal' external point load, F, results not only in pressure stress internally on account of R_Fn, but also in shear pressure on account of R_Fs. This can lead to distortion of tissue.

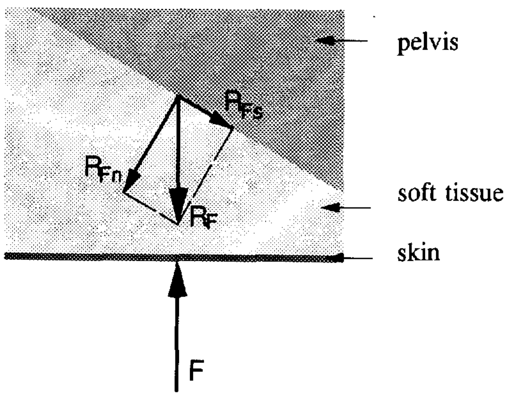


Figure 2-2 : External load F with internal reaction forces.

The internal shear force R_FS can be compensated by an equally strong opposing force. This might result for example in an external force F_2. In figure 2-3 we can see that $R_{F1}S$ and $R_{F2}S$ cancel each other out. The normal forces $R_{F2}N$ and $R_{F1}N$ reinforce each other.

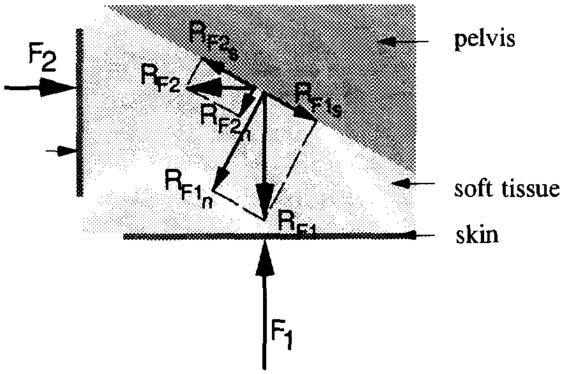


Figure 2-3 : External load F_1 and F_2 with internal reaction forces.

In actual fact the reaction of the supporting element to the load exerted by sitting consists of an infinite number of point loads, F. The distribution of F in F_1 and F_2 (and F_3: the third dimension) determines the eventual outcome internally.

We can compare the first example with a support consisting of a hard cushion. The impression made on it is slight. As a result lateral support is absent. Shear forces occur internally which distort the tissue. As the skin surface under load is relatively small, the reaction forces of the seat are high.
In the second example the support structure adapts to the shape of the buttocks and a lateral force F_2 is produced, which impedes the development of shear stress. Distortion of the tissue is slight or absent and by the enlargement of the surface under load, the tissue helps absorb the load to a large degree. On average this becomes lower causing even smaller pressure. Internal shear forces can be 'neutralised' by different directions of external load.

In addition to size and direction of the external load, equality is also a significant factor. Differences in pressure can lead to localised variations in volume due to interstitial moisturetransport. At the point at which these variations meet, 'suspension forces' (Meijer 1991) develop, wich have shear forces as components. These may have a detrimental effect on the cell walls, as has already been discussed. Figure 2-4 gives an illustration of the development of these shear forces at the surface where variations in volumes meet.

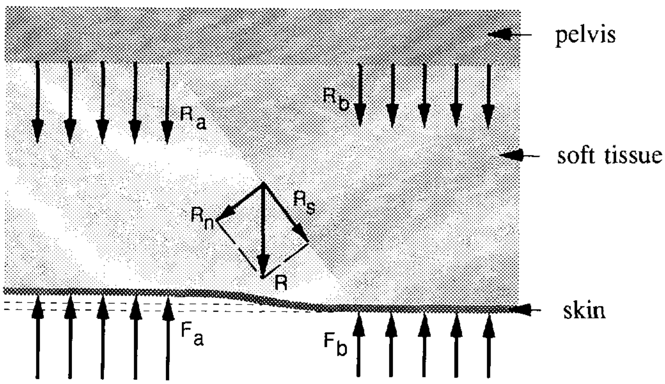


Figure 2-4 : The development of shear forces at the point where variations in volume - resulting from differences in pressure - meet.

Studies all seem to point towards the fact that decubitus develops internally in the vicinity of bone protrusions such as the ischial tuberosities. The internal pressure near to these protrusions is higher than directly beneath the skin and much higher than the so-called interface pressure which is measured between the skin and the supporting element. Le (1984) has established this fact in the case of pigs by taking *in vivo* internal measurements. A comparison of the 'internal' results taken from this study with those of the interface pressure, measured using the OPM (Oxford Pressure Monitor) under the 'test buttock' - a simulation of the human buttocks with built-in pressure sensors - , the very same picture is found. This subject matter is discussed further in section 4.4.

In general one aims to keep the level of maximum values for internal load as low as possible and to vary this load. Normal sitting behaviour is characterised by movement and changes in position. This means, bio-mechanically speaking, that new balances of forces are being constantly formed and that internally tissue is placed under continually changing loads.
The assumption is made here that dynamic sitting behaviour and, with it, variation in load might effectuate pumping action in the vascular system. This might maintain the flow of fluids and therefore the metabolics, despite the fact that internal pressure is higher than capillary pressure. This can only be

achieved on condition that the vessels have not been twisted closed as a result of distortion. This theory, or assumption, underlines the enormous influence which distortion and the associated internal shear forces have on the development of decubitus.
The pathology of decubitus is not present at all in normal sitting behaviour, despite the high to very high levels of pressures which occur.
Loads which give discomfort also give off stimuli which signal a change of movement and therefore a change in the load. If these stimuli are absent or a response to the signals cannot be given - as is the case for many wheelchair-users - , the process has to be influenced by two additional factors: the pressure-distribution properties of the cushion, which need to be optimal so that both the load on the areas around the ischial tuberosities and the level of disfiguration to the tissue are minimised; both major and minor changes in posture must ensure variation in load as well as the assumed pumping action. Variations in load should also maintain the volume of interstitial fluid at the same level.

To summarise it can be said that mechanical damage is caused by the emission of interstitial fluid under the influence of pressure and time, which enables distortion forces to act directly on the cell walls. Physiological damage is caused by a deficient metabolism over a prolonged period, which is caused primarily by the blockage of fluidmoisture flows. The level of internal load, the extent of distortion of the tissue and the length of time the load is exerted are strongly linked to the chances of developing decubitus.
The level of internal pressure and disfiguration are dependent on the size of the external load and the way in which this is applied. The size of the load depends in turn on the sitting posture, and the way in which this is transmitted onto the buttocks is determined largely by the qualities of the cushion.

2.3.2 Influence of moisture and heat on the development of decubitus

To some degree the moisture and heat regulating qualities of a cushion seem to be related to each other since outflow of moisture is accompanied by heatflow. The results from tests discussed in section 1.4.2 confirm this. The link between body heat and the production of sweat is also discussed in this section. In addition to moisture caused by the production of sweat, moisture caused by incontinence can also develop in the plane of contact between the seating surface and the sitting support.
The parts played by moisture and heat in the development of decubitus are very different, heat exerting mainly a physiological influence and moisture exerting a mechanical influence.

An increase in temperature of 1 °C generates a rise in cell metabolism of 10% (Fisher 1978). This means that the need for oxygen and nutrients rises correspondingly. Where closure of vessels prevents an adequate supply of oxygen and nutrients, tissue will be more quickly damaged.
Moisture softens the skin and enlarges the surface. We are all familiar with the phenomenon of wrinkled fingertips after spending a long time in the bath. Laboratory experiments on dissected pieces of skin in a controlled humidity environment show that tensile strength decreases by 75% when the relative humidity is increased from 10 to 98% (Stewart 1980).
The skin on an individual's behind has an important function in transmitting the load exerted by the weight of the upper part of the body to the sitting support and therefore has an important influence on the buttocks' own pressure-distribution qualities. A softened skin exerts a negative influence on this pressure-equalising quality. The analysis of pressure-distribution discussed in chapter 3 will elaborate on the function of the skin with regard to this.
In addition to their physiological and mechanical influences the presence of moisture and heat increases the chances of infection.

2.3.3 Risk factors in the development of decubitus

The primary cause of decubitus can be found in the constant distortion of tissue which brings about mechanical and/or physiological damage to the cell. Distortion is caused by external load. Without external load decubitus would therefore not exist! In preventing decubitus a distinction should be made between primary factors on the one hand, and risk factors which can have a negative influence on the primary process on the other.
The previous section dealt with how the development of decubitus might be accelerated by the effects of moisture and heat.
There are however, in addition to moisture and heat, other risk factors related to the individual or due to outside circumstances which may have a detrimental influence on the process. A summary of the previously mentioned factors plus a number of additional ones is summarised below.

Human-related factors, acting independently on external factors, include the following:

- little or no sensibility: the warning mechanism for overloading is ineffective or completely absent;
- atrophy: a reduction in the volume of muscle and fat tissue; this can lead to an unchanged weight i.e. the upper half of the body exerting much greater pressure on a reduced buttock surface; muscle and fat tissue form part of the buttocks' own pressure-distribution capacity: the less there is the higher the pressure exerted on the bone protrusions;

- the physiological and mechanical attributes of the skin;
  - the physiological quality of the skin can be measured by how the blood flow responds after a (test) load has been removed.
  - the tensile strength and elasticity of the skin are in some way dependent on the thickness of the skin, which varies per individual.
- reduced vascularisation caused by vascular disorders; this has an adverse effect on the metabolism;
- insufficient oxygen saturation of the tissue due to lung disorders;
- posture abnormalities and asymmetry due to scoliosis, contractures and bone formation can result in localised pressure increases;
- irregularities in the skin, e.g. scar tissue: this can lead to internal increases in pressure;
- excessive transpiration and incontinence.

The most significant risk factors which arise from user circumstances can be summarised as follows:
- the sitting posture:
  the sitting posture is responsible for size and direction of the external load given the supported body weight;
- cushion quality:
  e.g. the pressure-distribution capacity and moisture and heat regulation.

2.4 The relationship between the temperature reaction of the skin and the size of the external load

When using cushions in practice, the presence of erythema (superficial inflamation) on the buttocks provides an indication that pressure-distribution is not optimal. This is the way that tissue reacts to too long and too high a load. Bar (1988), in his doctoral thesis, makes an analysis of the relationship between the temperature reaction of the skin and the size of the external load. As the contents of this study provide an interesting and practically oriented addition to this chapter, a short summary is given of the research results.

Bar, in his thesis, presents the results of dynamic pressure readings taken over a period of 2 hours on 25 disabled test subjects on 3 different wheelchair-cushions: an unspecified model of Roho air cushion; a 5cm gel cushion on 2.5 cm layer of 'Aberdeen'-type foam (unknown in the Netherlands); and a 10 cm thick foam cushion with a density of 100 kg/m^3 protected with a vinyl cover. All test subjects had spinal cord lesions: 7 cervical, 13 thoracal and 5 lumbar. Data relating to hip width and weight are not provided. Sixteen test subjects used 10 cm thick foam cushions - whose respective qualities remain unspecified - with their own wheelchairs, 5 test subjects used a Roho cushion and two test subjects a gel cushion. For the remaining two persons the type of cushion used was not known. The Roho and the gel cushion were the same as used in the study. Only three individuals had a history of decubitus.

Bar measured the 'interface pressure' directly under the ischial tuberosities for a period of 2 hours using an improved OPM with a diameter of 28 mm in which air was replaced by liquid. Test subjects were left to pick and choose the tasks themselves.
The pressure readings which Bar measured under the right and left-hand tuberosities are illustrated in a pressure versus time histogram presented in figure 2-5. The pressures are presented at intervals of 30 mmHg and the times are set out vertically. Furthermore it would appear from the data in the histogram that in many cases the time duration exceeds 120 minutes by a long way.
Immediately following the pressure readings the erythema and the temperature of the skin under the tuberosities were measured in relation to time and noted down. Bar makes a distinction between 'marked erythema' and 'fading erythema'.

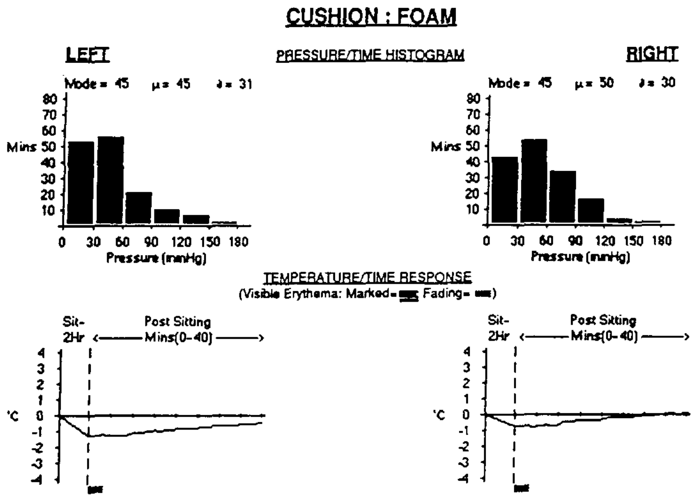


Figure 2-5 : Bar (1988) : example of pressure versus time histogram for left and right-hand buttocks recorded for one test subject over a period of two hours and the temperature reaction of the skin combined with the level of erythema on completion of the test.

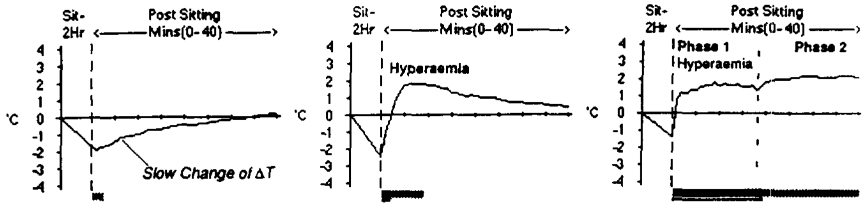
What is interesting about these histograms is the fact that the pressure on the ischial tuberosities appears to be a dynamic phenomenon. They illustrate that pressure, and with it load, can vary greatly over time. Individual differences in

pressure on the same cushions can also clearly be seen.
Furthermore there appears to be a relationship of some sort between the amount of external pressure, the thermal reaction of the skin and erythema. The thermal reaction of the skin is defined as being the difference in skin temperature of tissue under the greatest load directly under the tuberosities and tissue 5 cm away from the tuberosities in relation to the starting temperature for the test with the test subject lying in bed.

Bar identifies three types of skin reaction:
- the 'mild response' : this reaction appears to occur at average levels of external pressure smaller than 80 mmHg.
- the 'moderate response'; this appears to occur at average pressures of between 60 and 115 mmHg.
- the 'severe response' which is observed at average pressures of more than 90 mmHg.

This means that the difference between the 'mild' zone and the 'severe' zone is no more than 10 mmHg and that the 'moderate' zone generously overlaps the two.

In the case of 'mild response' no erythema was discernible. For 'moderate response' the 'marked erythema' disappeared within 12 minutes and completely faded away after a period of 20 to 30 minutes ('fading erythema'). In the case of 'severe response' the recorded levels of erythema were not much greater than those for 'moderate response', the difference being primarily in the temperature change on recovery as illustrated in figure 2-6.



Example of a Mild Response.
(Subject No. 4: µP =73 mmHg)

Example of a Moderate Response.
(Subject No. 19: µP = 68 mmHg)

Example of a Severe Response.
(Subject No. 2: µP = 148 mmHg)

Figure 2-6 : Bar (1988) : temperature response and erythema after two hours of sitting.

Bar makes the initial supposition that the skin response is independent of the

type of cushion used, but later concludes that this cannot be the case.
The difference in the temperature responses, defined between the foam and gel cushion and between the foam and the Roho cushion, appeared to be significant but not between the Roho and the gel cushion. The differences in average pressure readings were significant for all three cushions.
The average interface pressure readings under the ischial tuberosities were:

the foam cushion:	87.6 mmHg;
the gel cushion:	68.6 mmHg;
the Roho cushion:	50.6 mmHg.

These differences might be explained by the different heat regulation qualities of each of the cushions. Foam cushions have poor heat regulation qualities and in fact possess insulating qualities; gel cushions have a certain amount of temperature capacity which has an effect during the first few hours of use (see section 1.4.2) and air cushions with multiple cells have a reasonable heat regulation on account of the small openings between cells. The study in question measured differences in heatflow of 12 W/m^2, 29 W/m^2 and 34 W/m^2 respectively for comparable cushions (see table 6-4). The way in which the temperature response is defined can also play a role in this. The reference point, located 5 cm away from the tissue placed under the heaviest load, is after all itself placed under a load.

In additional tests using healthy subjects Bar establishes the relationship between externally applied pressure and the oxygen pressure pO_2 which can be measured on the skin. He used a model 33/34 Roche Electrode oxygen sensor for this purpose.
In the study the average pressure is situated between 80 and 110 mmHg whereby the pO_2 approaches 0 at 100 mmHg.
This so-called 'cut-off pressure' is used in the pressure versus time histogram to calculate the relationship between the time during which 'oxygen debt' (D) may occur due to pressures of more than 100 mmHg, and the time during which 'oxygen recovery' may occur due to pressures of lower then 100 mmHg.
Bar defines the relationship (R/D) as an indication of tissue condition. He infers that decubitus is caused by a process of ischaemia or an inadequate flow of blood.

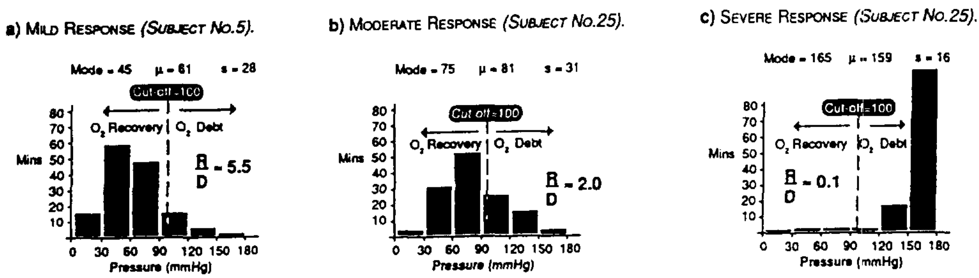


Figure 2-7 : Bar (1988) : Examples of R/D ratios for three distinctive skin responses.

These ratios demonstrate that the 'oxygen recovery' time for e.g. a 'moderate response' is on average 2.4 times more than the time for 'oxygen debt'. This ratio factor averages 7.8 for a 'mild response'. This result on its own suggests that these terms are not completely adequate and do not indicate the actual situation within the tissue.
Bar establishes that the pO_2 level recovers only at a slow rate when the tissue is relieved of its load. For this reason he concludes periodic lifting as being inadequate since the recovery time would be too short to make up for the oxygen shortage. However, he does not extend this argument to the calculations he makes for oxygen debt and oxygen recovery as presented in the time versus pressure histograms.

The influence of the dynamics of load on the internal pressure-distribution and the assumed pumping action (as surmised in section 2.3.1) are not dealt with by Bar. His rejection of the effects of lifting ignores other effects which might materialise. Lifting can bring about a new equilibrium in internal and external forces which, at cell level, can set in motion significant changes which may well prevent damage to tissue deeper under the surface. It is possible that lifting, despite the fact that the change in internal load is momentary, plays an important role in the recovery of interstitial moisture volume, thus exercising a positive effect on the Reswick and Rogers curve.

In his arguments with respect to 'oxygen recovery' Bar also probably overlooks the fact that his interface pressure readings are 2 to 3 times lower than the pressure which can be measured internally in the vicinity of bone protrusions (Le 1984). The internal pressure is nearly always higher than the capillary pressure and will result in the blockage of vessels.

Bar subsequently makes the link between the R/D ratios revealed in the study and the defined tissue responses.
This is shown in figure 2-8.

RESPONSES (n = 150)*	R/D Ratio $\mu \pm s$	μP (mmHg)
Mild (n=102)	7.8 ±4.6	≤ 80
Moderate (n=24)	2.4 ±1.9	60 -115
Severe (n=24)	0.6 ±0.5	≥ 90

* mean of dynamic pressure

Figure 2-8 : Bar (1988) : relationship between average interface pressure: μP, the R/D ratio and the defined skin responses: mild, moderate and severe.

The value of Bar's study lies primarily in the fact that the dynamics of load have been recorded and that the link is made between the skin response and the average interface pressure value.
In section 4.5.1 an analysis is made of the possible link between Bar's findings and the assessment criteria for pressure-distribution qualities as supported in this study. The conclusion, made that there is a certain amount of correspondence, will have to be treated with a degree of caution.

2.5 Summary and conclusions

The wheelchair-user who is forced to adopt a sitting position as a result of a physical impairment is faced with a number of complications which can be prevented or eliminated by an active or passive simulation of natural sitting behaviour combined with an optimisation of the sitting conditions.
Sitting in a wheelchair is subject to the same 'principles' as those applying to a 'normal sitting posture'. It is not only important but also vital to optimise the balance of forces which are brought about by a sitting posture, since sensibility can lead to a change in posture when overloading is present, a feature which is frequently lacking in wheelchair-users.
The sitting posture can and should be used to compensate for the physical incapacity. The sitting posture can facilitate stability of the trunk, if this is required as a result of incapacity. The upper part of the body's line of action of gravity in relation to the lumbar 'pivot point' is an important aspect here, and applies equally so when the back is immobile. A form of instability may indeed develop which exerts a moment on the lumbar spinal column which in turn may lead to kyphosis of the lumbar spine in the long term.
By adapting the sitting posture to a 'task' a natural sitting behaviour emerges which is accompanied by a necessary variation in load. The wheelchair should of course be capable of facilitating this action.

The cushion's features determine the sitting environment and the pressure-distribution which develops per individual. A number of pertinent characteristics regarding the cushion user and the use of the cushion can be discerned in respect of cushion attributes. Using these characteristics we can identify three groups of users and three types of user conditions. User conditions are related to the design and construction of the cushion. On the basis of this information a total of 5 cushion types was selected.
Apart from the pressure-distribution qualities of the cushion, its moisture and temperature regulating properties are important elements in determining the level of comfort. If this is sufficient it will have a positive influence on the prevention of decubitus.
Decubitus is primarily caused by constant deformation of tissue which in turn damages the cells mechanically and/or physiologically. Distortion is caused by external load. Risk factors both in respect of the individual and the user conditions may also play a role in the development of decubitus.
The lowest internal pressures measured under the ischial tuberosities are at least 2 times as high as the capillary pressure of 30 mmHg. This means that in- and outflow systems become blocked as a result of sitting load. Blockage of these systems can, over a prolonged period, have damaging physiological effects. Very high localised pressures can lead to mechanical damage of the cell. There appears to be a clinically established acceptable level between the amount of external load (i.e. the interface pressure) and time.
The effect of time on the development of decubitus is not only influenced by the excessive deficiency in nutrients to the cell, but also by the discharge of interstitial fluid between the cells when placed under load. It is feasible to imagine that, as a result of this, cells are damaged mechanically at a faster rate. As the interface pressure on the ischial tuberosities is only half of that of internal pressure, it is an astonishing fact that so few people actually suffer from decubitus. It would therefore appear that there are regulating mechanisms and circumstances which help keep the nutritional processes in working order. One of these regulating mechanisms might take place in situations where the almost ever-present dynamics of the load facilitates a kind of pumping action which in turn temporarily sets the transport of nutrients in motion. A condition for this taking place is that the vessels have not been twisted closed as a result of the load placed upon them. Shear forces in the tissue, in particular, are held responsible for this.
The effect of load size on the buttocks can be tested using the temperature responses of the skin after the pressure is removed. Bar (1988), in a study using 25 test subjects with spinal cord lesions, established temperature responses of the skin in relation to the average pressure measured over a period of two hours. He divides temperature responses into three categories; 'mild', 'moderate' and 'severe', linked to pressure intervals in which they are recorded. Between the 'mild' and 'severe' areas there is only a difference of 10 mmHg. The 'moderate' area overlaps this disparity.

3.0 Analysis of pressure-distribution

Pressure-distribution during sitting is brought about by interaction between the characteristics of the sitting support and the characteristics of the buttocks. Section 1.4.1 lists a number of characteristics relating to the individual and a number of characteristics relating to the cushion which influence this process. A general pattern is identified in respect of the so-called interface pressure. This pressure can be measured between an individual's buttocks and the sitting support. This pattern reveals that the highest pressure is likely to occur directly underneath the ischial tuberosities. A sitting support's pressure-distribution is understood to be its capacity to spread the load across the buttocks in such a way that pressure under the ischial tuberosities is minimised. Low pressure levels not only give a feeling of comfort but are also an important factor in the prevention of decubitus amongst wheelchair-users, as already discussed in section 2.3. This section also analysed the way in which external load is transmitted internally and how shear forces can develop internally.

This chapter will elaborate further on the interaction between characteristics of the buttocks and the properties of a sitting support. The question will be addressed as to how satisfactory levels of pressure-distribution can be achieved on the basis of this interaction.
An understanding of how pressure-distribution is effectuated in or by a cushion is not only necessary for effective cushion design but also in the optimum application of cushions in individual situations, especially in situations where the cushion's primary function is to prevent decubitus.

Despite many publications on this subject the tools required to carry out the analysis of pressure-distribution are minimal. Most studies limit themselves to an examination and presentation of results of pressure-distribution tests carried out on a number of different cushions using a small test population. Smaller than average maximum pressure values, when measured across the whole of the test population, are taken as proof that one particular cushion is qualitatively better than another. Analyses of why one individual should achieve a better pressure-distribution using a particular cushion as opposed to another, are thin on the ground even though this information which might result from this could be effectively applied in case treatment. Analyses of the reasons why one particular cushion is better than another are few and far between. Important test conditions such as the sitting posture and the support structure are not specified unless they form the central theme of the study (e.g. Hobson 1992, Engel 1986). Results are often related to the materials used or the systems applied and then generalised (e.g. Bar 1988, Goossens 1994). The lay reader might be forgiven for thinking that he has lost his bearings. The analysis which follows in our present study will demonstrate that satisfactory results can be achieved using a wide range of materials as long as the underlying principles themselves are followed.

As part of the analysis of the pressure distributing performance of cushions this chapter will make recourse to a number of test results from simple experiments using foam as a pressure-distributing medium, in order to develop these principles of application. The conclusions drawn from this exercise will be used to explain the performance of air and water filled cushions.
Test data for this analysis will be based on readings for the maximum internal pressures, taken on the ischial tuberosities of a test dummy which in shape, size and structure closely resembled human buttocks. The test dummy is discussed in more detail in chapter 4. The order in which the subject matter is treated in this study has been made on the assumption that a basic understanding of the pressure-distribution phenomena is required before the problems of defining pressure-distribution qualities of cushions can be understood.

3.1 Structure of the buttocks and the cushion

In order to understand how a cushion works it is necessary to analyse the structure and shape not only of the cushion but also of the buttocks. If we take a closer look at the structure of the buttocks we will see that in many ways they resemble the structure of a cushion. Both the buttocks and the cushion have structures in which 'hard', non-deformable parts as well as 'soft', deformable parts can be identified. Likewise these deformable and non-deformable parts are contained within an outer 'sealing'.
The human posterior consists of the pelvis which is surrounded by soft tissue and sealed by skin. The weight of the upper part of the body is transmitted by way of the spinal column into the pelvis. In effect, the skin has the function of holding the mass of soft muscle and fat tissue together. The softer parts combine together with the skin to form a pressure-distributing medium in relation to the pelvis.
The cushion is also composed of deformable and non-deformable parts. The non-deformable parts transfer the reaction forces of the chair frame to the deformable parts of the cushion. In turn the soft parts of the cushion act as a pressure-distributing medium on the buttocks. Figure 3-1 depicts the structure of the buttocks and the cushion.

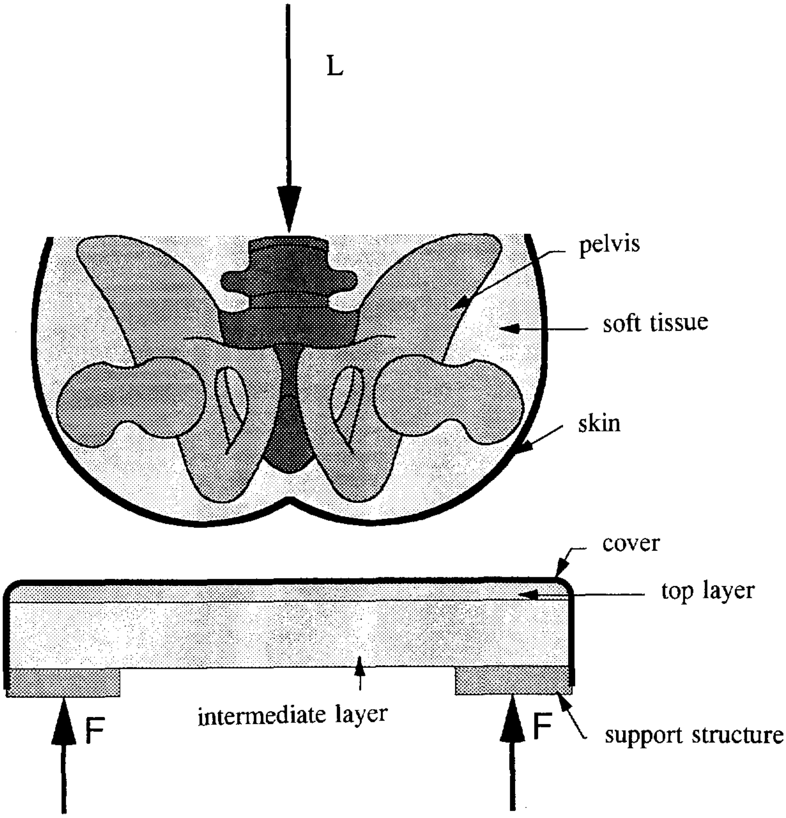


Figure 3-1 : Structure of the buttocks and cushion in the frontal cross-section of the ischia.

How is pressure-distribution derived?
When an individual sits down the buttocks and the cushion, both similar structures, press up against each other.
The way in which these structures respond to each other depends on the characteristics ascribed to the 'materials' involved.
If the cushion's 'resistance to deformation' is greater than the buttocks' 'resistance to deformation' then the buttocks will deform. If, conversely, the cushion's 'resistance to deformation' is smaller than that of the buttocks then the cushion will adapt to the shape of the buttock.
The notion that the buttocks form a structure with a specific individual shape and mass of soft material which cannot be remoulded, is important in this respect. The shape and composition of the cushion on the other hand can be selected and, if necessary, should be in conformity with the shape of the

buttocks.
The ultimate objective is to minimise the pressure exerted on the ischial tuberosities and to prevent deformation of the buttocks.

3.2 Pressure-distribution performance of foam cushions

A general characteristic of foam is that its reaction force as a result of indentation increases, the greater the indentation becomes. When an increase in indentation is no longer possible, even when load is increased, this is called 'bottoming'. A general load-indentation graph for foam is shown in figure 3-2.

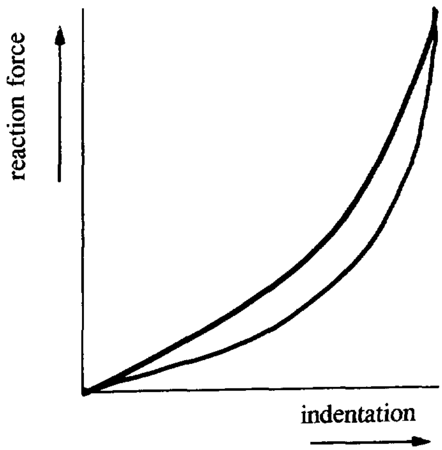


Figure 3-2 : Generalised relationship between load and indentation in respect of foam.

In order to gain a better understanding of how pressure distributing properties of a foam cushion work, a number of simple experiments were carried out. Firstly the influence, which the thickness of foam has on the pressure under the ischial tuberosities, was monitored. For the purposes of this experiment DRAKA 9018 foam was used with a density of 35 kg/m^3 and a hardness of 110 N based on DIN 53577. This foam is a commonly used type in cushions. The foam was placed on a hard flat board which served as a support structure. The foam was subjected to a load, consisting of a 600 N test dummy. The test dummy, as previously mentioned, resembles the shape, size and structure of human buttocks and is discussed in more detail in chapter 4.

The results of these experiments are shown in table 3-1. The pressure under the ischial tuberosities appears to decrease as the thickness of the foam increases.

	thickness mm	max. pressure mmHg	absolute indentation mm	relative indentation %
Foam Draka 9018 on flat board	60	319	50.5	84
	80	216	60.9	76
	100	161	73.8	74
	120	126	73.3	61

Table 3-1 : The influence of foam thickness on indentation, pressure and relative indentation, measured under the ischial tuberosities, for a load of 600 N using a test dummy.

Absolute indentation increases with the thickness of the foam except in the changeover from 100 mm to 120 mm thickness. This means that the test dummy sinks yet deeper into the cushion. The surface under load is enlarged as a result of this increase whereby the average pressure and apparently the maximum pressure decrease. The figures recorded for relative indentation, arrived at by dividing the absolute indentation by the original thickness, are worthy of note. The decline in maximum pressure is more or less proportional to that of the relative indentation: the lower the relative indentation, i.e. deformation of the foam, the lower the maximum pressure.

What can also be concluded form this data is that the characteristics of foam with similar thicknesses can be compared effectively by their load-indentation relationship. Moreover we can conclude that, for situations where foam is used in supporting elements, thickness and relative indentation are the most significant factors in determining the load situation and, in this case, maximum recorded pressure.

3.2.1 Influence of the support structure on maximum pressure

A piece of 80 mm thick Draka 9018 foam, which gave a maximum pressure-reading on the tuberosities of 216 mmHg, was placed on a so-called 'trampoline'. The trampoline consisted of a wooden frame in which an open fabric was suspended. The fabric when subjected to a load sags by about 4 cm, depending of course on tautness with which the cushion has been fixed to the frame. The trampoline can best be compared to the sling type sittings used in wheelchairs, though these are suspended in two directions. The result of this combination, i.e. the foam 'cushion' and the trampoline, produced an improvement, i.e. a decrease, in maximum pressure. The 216 mmHg measured in the previous test now became 117 mmHg, almost half of the original pressure reading. The results are compared in table 3-2.

	thickness mm	max. pressure mmHg	absolute indentation mm	relative indentation foam %
Foam Draka 9018 on flat board	60	319	50.5	84
	80	216	60.9	76
	100	161	73.8	74
	120	126	73.3	61
Foam Draka 9018 on a trampoline	80	117	total:70 trampoline:40 foam:30	37

Table 3-2 : Influence of the support structure on the maximum pressure under the tuberosities for 80 mm thick foam: Draka 9018.

If we deduct the trampoline's 40 mm sag from the absolute indentation of 70 mm for the foam on the trampoline and then calculate the remaining relative indentation, it is reduced to 37%, half of the original 76%.

This result can be accounted for by the fact that the foam on the trampoline requires a smaller degree of deformation, in order to accommodate the contours of the buttock, whilst the surface under load is increased at the same time. With small, even indentations in the foam a balance of forces is achieved. Small levels of indentation also mean lower reaction forces. For the cushion which was placed on the flat board the level of indentation is high, and at its highest directly under the tuberosities. This is also where the reaction forces of the foam will be greatest. The simple conclusion we can draw from this exercise is that in this case the support structure plays an important role here in forming the shape of the buttocks in the foam, when subjected to load without causing any great deformation in respect of the foam. Indentation in the foam is small and even, whilst an enlarged surface under load is realised.

This enlargement however is not sufficient to explain the spectacular 50% reduction in maximum pressure. An enlargement in the surface under load by 1 cm means roughly a 10% increase in the surface area. In theory the average pressure will be reduced by around 10%. The decrease in maximum pressure is however much greater and can best be accounted for by the fact that the modest size of the foam's reaction forces do not deform the buttocks, meaning that their *shape* remains intact, thus optimising the pressure-distributing capacity of the buttocks themselves.

In order to evaluate this proposition, the mould, which was used to manufacture the test dummy, was deployed as a sitting support. This sitting support can be described as a hard contoured shell which almost perfectly matches the shape of the buttocks, but which allows absolutely no possibility for indentation (i.e. adaption). In effect the measurements refer to the test dummy's own pressure distributing capacity when its shape is left intact. In table 3-3 we can see that the results of this have been added to those of the previous table as well as the results of the test dummy on a flat board.

	thickness mm	max pressure mmHg	absolute indentation mm	relative indentation foam %
Foam Draka 9018 on flat board	60	319	50.5	84
	80	216	60.9	76
	100	161	73.8	74
	120	126	73.3	61
Foam Draka 9018 on a trampoline	80	117	total:70 trampoline:40 foam:30	37
Hard contoured shell: mould	-	153	0	

Table 3-3 : Influence of the sitting support on maximum pressure when fully adapted to the shape of the buttocks.

The result is not as good as that for the 80 mm foam on the trampoline, but better than that for the 100 mm foam on the flat board. Since the mould is essentially a support structure without a pressure-distributing medium but which is fully adapted to the shape of the buttocks, the result can be considered

as being brought about by the buttocks' own pressure distributing capacity when its shape remains intact.
As a result of this the conclusion might be that the buttocks' own pressure-distributing capacity is astonishingly high if the conditions stated are met. A cushion will therefore develop satisfactory pressure-distribution when it is able to make maximum use of the buttocks' own pressure-distributing capacity. This is achieved when the cushion, under load, assumes the shape of the buttocks without deforming them. When foam is used as a pressure-distributing medium, the support structure can play a significant part in helping to effectuate adaptation to the shape of the buttocks.
Another conclusion, which can be drawn from these and other results taken from pressure-distribution studies in respect of individuals (Engel 1986, Chung 1988), is that every pair of buttocks possesses its very own pressure distributing capacity depending on the size, shape and structure of hard and soft parts which act in combination with sitting weight.

Pressure-distribution capacity will be increased in proportion to the level of harmonisation between the support structure and the properties of the foam in respect to each other and in respect to the shape and size of the user's buttocks. Chapter 7 describes a number of test cushions which were developed and used in experiments with different types of support structure and different types of pressure distributing media.

3.2.2 Influence of the cover on pressure-distribution for foam cushions

All the experiments done with foam were, up to this point, carried out without using a cover. Table 3-4 lists results for tests carried out using a number of different kinds of covers for an 80 mm foam trampoline cushion.
The evidence is that the cover has a significant influence on pressure-distribution. As a rule of thumb it can be said that the stiffer a cover is, the more the maximum pressure is likely to be. This cannot however be said for hydrolon, as this is a material which is quite thin and supple, though the rigidity of the silicone coating might well be a factor accounting for its relatively high maximum pressure.
The degree of influence that the cover has on the pressure-distribution qualities of a cushion can be accounted for by so-called the 'hammock effect'. The origin of the hammock effect can be explained by the fact that a disparity exists between the projected surface of the buttocks before the load is applied

	max. pressure mmHg
Draka 9018 80 mm foam on trampoline	
without cover	117
with thin stretch material	117
with thick woollen fabric	135
with thick stretch material	141
with imitation leather	152
with hydrolon: thin fabric with silicone layer	146
with coated woven fabric	163

Table 3-4 : Influence of the cover on the pressure under the ischial tuberosities (mmHg).

and the actual surface during load. The difference must be initiated at some point during the sitting-down process. Figure 3-3 shows that this originates at the sides of the cushion.

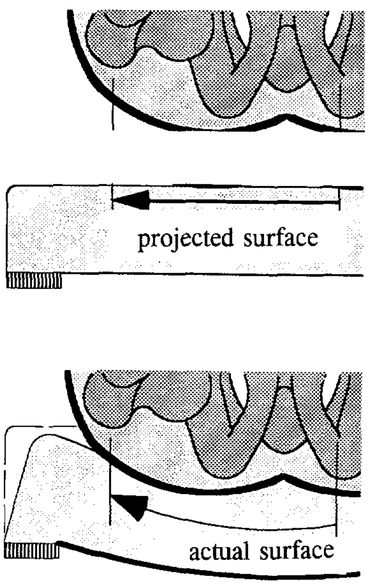
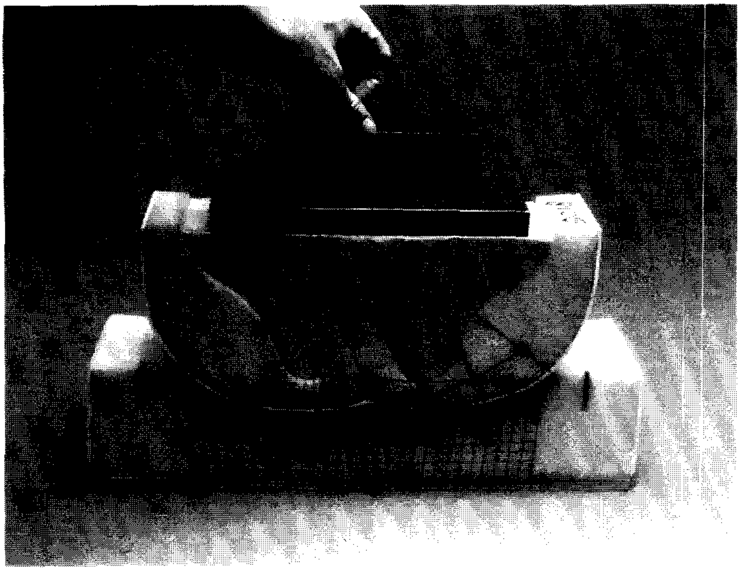


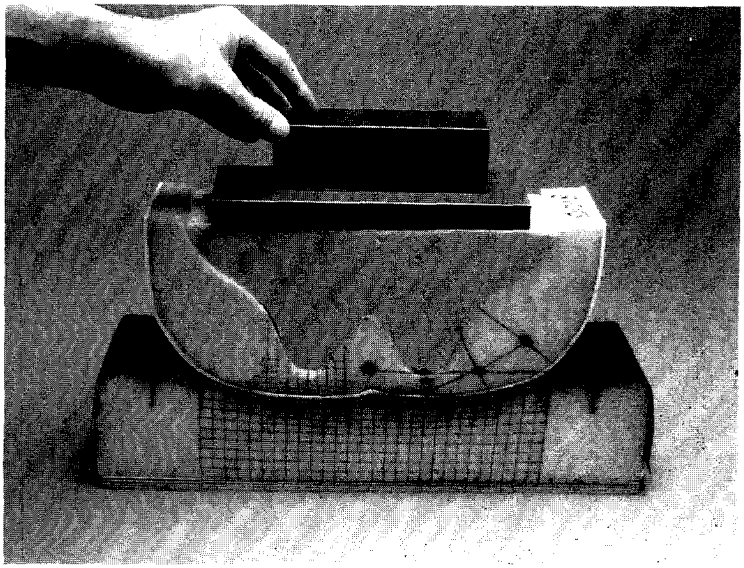
Figure 3-3 : The difference between the projected surface and the actual surface.

The deformation of foam in a horizontal plane which accompanies this produces a reaction force F_R which offers resistance to this deformation. The tensile stress in the surface under load shows a tendency to stretch the surface once more. This tendency prevents the surface from fully assuming the shape of the buttocks.
This increases pressure on the tuberosities since in the main it is the buttocks which are flattened out as a result of the tensile stress.
The 'hammock effect' can be best identified with the aid of a model which was designed for this purpose. The effect on the non-elastic cushion on the size of the indentation can be clearly seen in photograph 1 and photograph 2. The photos were both taken from the same standpoint. The indentation of the cushion in photograph 1 is clearly greater than in photograph 2. The effect of this on pressure-distribution can quite clearly be seen on account of the thickness of the foam under the tuberosities of the test dummy. The distance in photograph 1 is greater than in photograph 2.



Photograph 1 : Indentation in partly cut foam without cover.

It is clear that with the help of a range of different types of cover the hammock effect shown here also occurs in the foam despite the protection of a cover when the foam has an unimpaired horizontal structure. The cover reinforces this effect. The cover indents the foam at the sides causing reaction force Ft. Without the cover the deformation caused by the buttocks will 'pull' the foam in a horizontal direction causing the reaction force. In the latter situation the reaction force will probably be somewhat smaller as a result of the foam's elasticity.



Photograph 2 : Indentation in partly cut foam with imitation leather cover.

By cutting into the foam, either completely or partially, its horizontal structure is eliminated, preventing the occurrence of tensile force.
To summarise, we can identify two types of reaction forces which together counterbalance the load L:
The vertical reaction forces caused by indentation; and the horizontal force caused by the 'hammock effect' which sets in motion a small vertical component: F_{Rh}.

$$L = F_{R_{indentation}} + F_{R_{hammock}}$$

This balance of forces is schematised in figure 3-4.

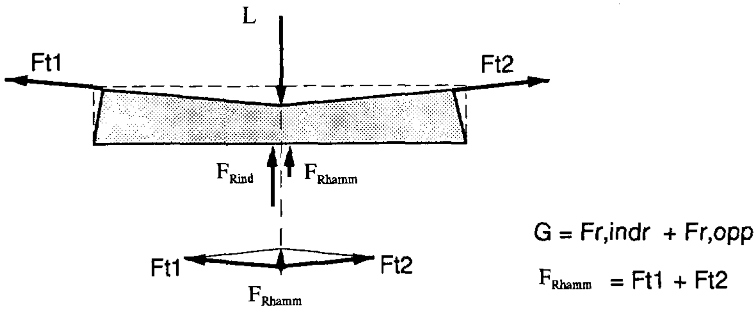


Figure 3-4 : Schematised model of the interplay of forces in a cushion under load.

The uniformity and size of these reaction forces caused by cushion indentation will largely depend on the shape of the support structure under load, as has been previously shown. The more this shape resembles the shape of the buttocks the more equal and smaller the indentation of the foam will be and with it the reaction forces. Figure 3-5 illustrates this for a cross-section. The same effect indeed applies to a longitudinal section.

The average pressure diminishes when the surface under load is relatively large. Smaller indentation of the foam also has the effect therefore of reducing any possible 'hammock effect' which may occur. The result is therefore twofold.

Solving the 'hammock effect' practically can be done by dividing the surface into smaller sections. To achieve this, the foam is cut in two directions. As a result the indentation characteristics of the foam are indeed modified. To achieve the best result, an elasticated stretch cover should be used; otherwise the effect will be nullified.

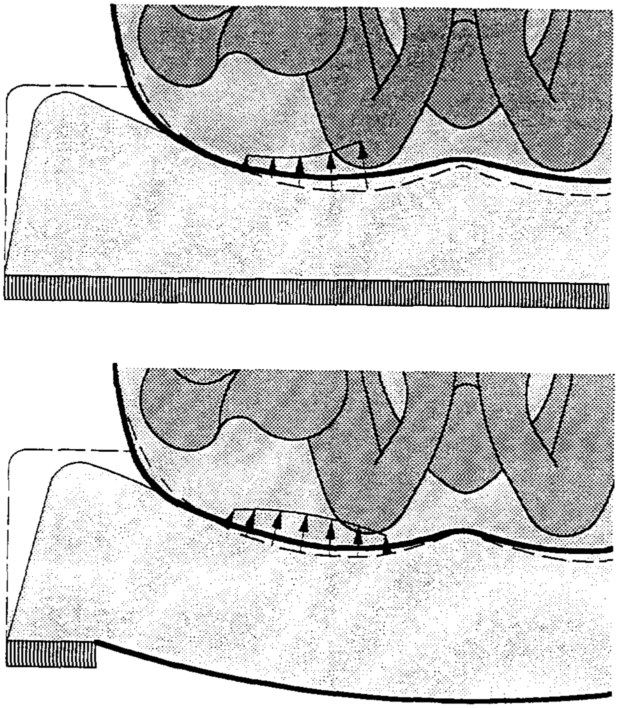


Figure 3-5 : Influence of the shape of the support structure on the uniformity of the indentation in cross-section.

3.2.3 Conclusion

The pressure-distribution performance of a foam cushion can be analysed and understood by asking four questions:

- to what extent does the support structure contribute to a change in the shape of an individual's buttocks? In other words: what level of deformation, or in this case indentation, is the foam expected to attain?
- how is the link between indentation and reaction forces of foam realised and what level of relative indentation is achieved?
- to what extent does (undesirable) tensile stress occur in the surface under load as a whole and what is the effect of the cover on this phenomenon?
- has anything been undertaken to reduce the reaction forces operating on the ischial tuberosities?

This last question has not been addressed in these experiments, but can in theory be applied to a cushion to improve the results yet further. For example a less hard foam material might be used in the locality of the ischial tuberosities. Chapter 7 discusses the application of foam material in test cushions and presents the results of these experiments.

3.3 The performance of air and water filled cushions

The essential difference between foam cushions on the one hand and air- and water-filled cushions on the other hand is in the relationship between indentation and reaction force. For foam cushions the reaction force increases slowly in proportion to the indentation. For air- and water-filled cushions hardly any reaction force occurs during indentation and balance is achieved almost immediately. A pneumatic or hydrostatic pressure occurs within the system, the level of which is determined by size of load L and the area of the surface S under load.

As a formula: $p = L / S$

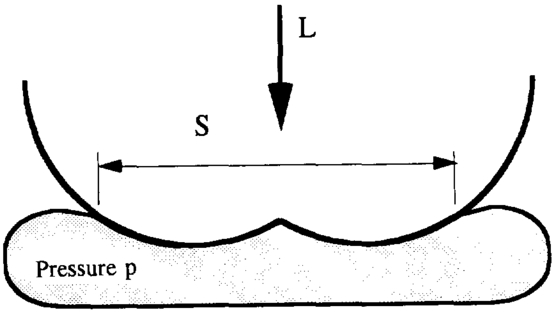


Figure 3-6 : Influence of the area of the surface under load on the size of pneumatic or hydrostatic pressure.

In practice this means that the balance is adjusted according to cushion design and the level to which it is filled, i.e. the amount of air or water in the system, the size and shape of the buttocks and the size of the sitting weight.

To clarify this two examples are given:

A sitting weight of 600 N on 1000 cm^2 of buttock surface gives a pressure in the system of 45mmHg, on 1200 cm^2 38 mmHg.

In theory this pressure forms a uniform external load when tensile stresses in the cushion sealing would not occur by the pneumatic or hydrostatic pressure. These tensile stresses produce the same effect as the 'hammock effect' discussed earlier and impede conformity to the shape of the buttocks.
The size of this tensile stress, which occurs in this type of pressure-distributing medium, is directly proportional to the size of the pneumatic or hydrostatic pressure p in the system. Pressure p in the system not only needs to be kept to a minimum on account of pressure-distribution but also in order to minimise the hammock effect.

The degree to which conformity can be realised depends therefore on the tensile stress which is produced in the surface under load in its entirety as a result of pneumatic or hydrostatic pressure in the system. The level of pneumatic or hydrostatic pressure depends in turn, firstly, on the amount of air or water in the system, since for low pressures the buttocks must be able to sink to a sufficient depth, and, secondly, on the size and shape of the buttocks. Krouskop (1986) after analysing 14 test subjects with differing postures found that the average optimum interface pressure for an air-pressure of 35 mmHg with individual optima lay between 23 and 46 mmHg.

There are two basic solutions with regard to air- and water-filled cushions. These are:
- an air/water cushion whose surface consists of a single component,
- an air/water cushion whose surface is divided into a number of smaller components.

Both solutions exist in different versions:
- the cushion comprises one single air/water cell: all smaller cells, if any at all, are connected to each other, or
- a partition has been made between the left and the right-hand sides to take into account improved sitting stability.

Both principles are illustrated in figure 3-7 and 3-8 respectively.

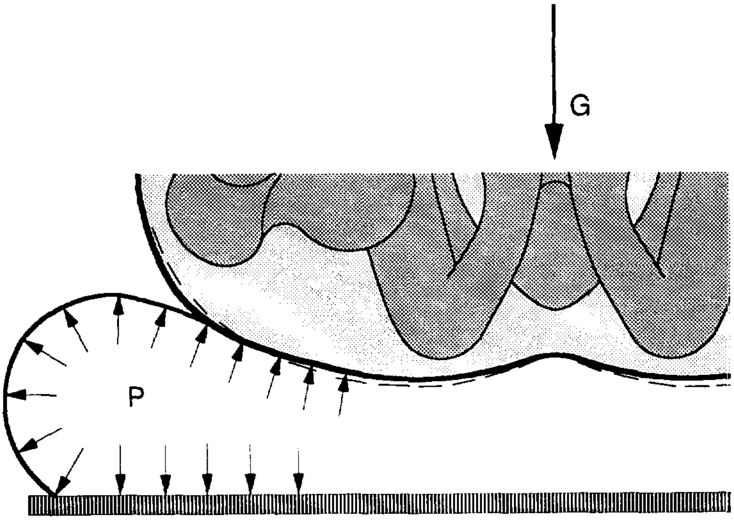


Figure 3-7 : Air cushion consisting of a single cell.

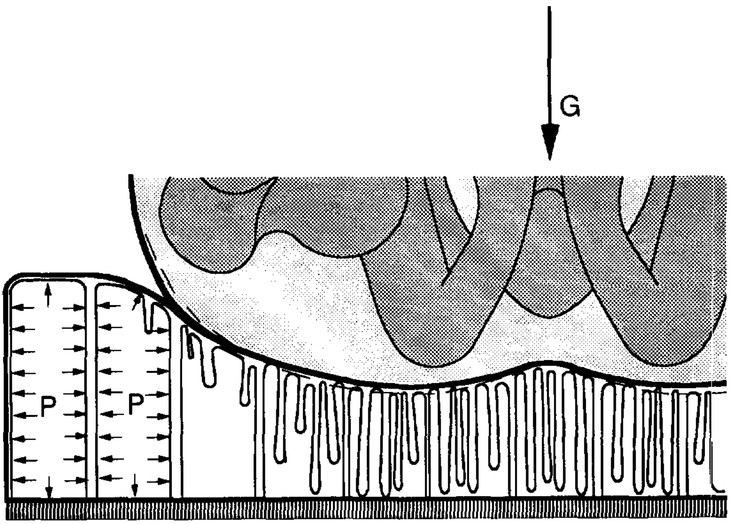


Figure 3-8 : Air cushion consisting of a number of cells and fitted with an elasticated cover.

In both cases the level of pressure p depends on the size of the surface under load. If the surface under load is the same, the pneumatic or hydrostatic pressure will also be equal.

For cushions incorporating one cell only, the pneumatic pressure will result in tensile stress in the surface under load, which may manifest itself as the hammock effect preventing full conformity. Higher pressures will be observed internally under the ischial tuberosities.
For air-cushions, which consist of a number of air cells, the surface under load is divided into small individual sections, so that no tensile stress at all can develop on the surface under load in its entirety. The prospect of the hammock effect will therefore be eliminated. It does, however, occur in each of the individual cells, but the effect on the resulting conformity is minimal.
The material properties of the cushion casing in combination with the nature of the deformation of cells has a bearing on the development of hard or soft 'edges', which may result in localised areas of higher pressure.
The results of pressure readings for different types of air- and water-filled cushions is discussed in section 5.3.

To finalise this general analysis, a few remarks concerning the difference between air filled, water filled, fluidised gel and non-fluidised gel cushions need to be made. There are no fundamental differences between air filled, water filled and fluidised gel cushions in respect to pressure-distribution. Apart from minor differences caused by variations in density, in all cases pressure is dependent on the size of the surface under load, whereas the tensile stress in the cushion casing is dependent on pressure p in the system. The extent to which this tensile stress impedes conformity is related to the extent to which the tensile stress occurs in the surface under load *in its entirety*.

The difference between air filled, water filled and fluidised gel cushions manifests itself in the form of other characteristics which are related to the compression capacity of the pressure-distribution medium used, which air has, but water does not, e.g. in relation to density and heat capacity. These will be discussed in chapter 6.

Non-fluidised gel can best be compared to a stiff foam, as the reaction forces of the gel cushion in all probability depend on indentation. Section 5.4 discusses the pressure-distribution properties of these types of cushion.

3.4 The performance of combined pressure distributing media

There is a large number of cushions on the market today which incorporate a number of pressure distributing media, such as:
- fluidised gel on a layer of foam
- foam - fluidised gel - foam
- an aircell system embedded in foam

- foam padding in an air-filled cushion consisting of one cell only
- etc, etc.

Sometimes these cushions incorporate their own support structures, but as a rule they do not. More often than not a recommended support structure is not included when the cushion is supplied.

The reason for combining different pressure distributing materials is not just for the purposes of pressure-distribution but also on the basis of other important attributes such as stability, surface softness, shock absorption, heat regulation etc.
Every system has its pros and cons. By imaginative combinations one can try to minimise the disadvantages whilst at the same time maximising the advantages. Chapter 6 analyses the influence of materials on cushion characteristics.
The pressure-distribution performance of these hybrid cushions can in theory be explained and interpreted on the same basis as for foam and air/water filled cushions discussed in the previous sections. During indentation however a 'counteractive' element on the one hand may develop between the different materials, but on the other hand a 'cooperative' element may be present.
The use of foam *within* an air-filled cushion, consisting of a single cell, produces, depending on the indentation characteristics of the foam, a pneumatic pressure which is, or may be, relatively lower due to the reaction forces of the foam. The effect of this is a relatively small tensile stress in the surface under load.
The use of a number of air cells embedded in foam results in the surface of the air cells under load becoming smaller, causing higher pneumatic pressure. It will depend on the indentation characteristics of foam to what extent the foam will accommodate the buttocks.
The use of fluidised gel 'pockets' on or in foam has probably its greatest influence on heat regulation.

3.5 Summary and conclusions

The human posterior consists of the pelvis which is surrounded by soft tissues and sealed by skin. The weight of the upper part of the body is transmitted by way of the spinal column into the pelvis. The skin has the function of holding the mass of soft muscle and fat tissue together. The softer parts in combination with the skin form a pressure-distributing medium for the pelvis.
The pressure-distribution of the buttocks is at its most effective when their shape is maintained under load.

The pressure-distribution performance of a cushion is aimed at maintaining the shape of the buttocks when placed under a load. The cushion must adapt to the shape of the buttocks without such deformation of the cushion leading to high reaction forces. The shape of the support structure and the characteristics of the pressure-distributing medium are major contributing factors.
There is a fundamental difference between the performance of foam cushions and the performance of air filled and fluidised cushions. The deformation of foam produces a reaction force which increases in proportion to the increase in deformation, i.e. indentation. In a number of concrete cases the relative deformation appears to play an important role. The reaction force of air-filled and fluidised cushions depends on the way the surface reacts under load. The characteristics of the cover, or in the case of air-filled and fluidised cushions, the cushion sealing can exert a negative influence on pressure-distribution, since, when subjected to a load, it can, in combination with the pressure-distributing medium, bring about tensile stress in the surface under load which in turn impedes full conformity. There is a positive relationship between the pneumatic or hydrostatic pressure in the system and the tensile strength stated. The tensile strength in the surface under load can be positively affected by dividing the surface into a number of smaller surfaces.

The pressure distributing performance of a cushion chosen at random can be analysed and understood in theory by providing answers to the following four questions:

- To what extent does the support structure contribute to the conformity with the shape of the buttocks? In other words to what extent will the pressure-distributing medium be indented, or - in the case of foam - what level of relative pressure will be produced?
- What is the link between the indentation and reaction force of the pressure-distributing medium being used?
- To what extent does an (undesirable) tensile stress develop in the surface under load in its entirety and what is the influence of the cover on this phenomenon?
- Is the principle of pressure-distribution capable of reducing localised reaction forces under the ischial tuberosities?

The various systems, materials and structures each have their individual advantages and limitations. Chapter 5 will examine in more detail the different approaches using the results of the investigation.

4.0 Measuring pressure-distribution

The way in which a cushion distributes pressure when an individual is sitting, is an important factor in determining the level of comfort. For wheelchair-users it has the special task of preventing decubitus. In addition to a number of factors relating to the individual, such as weight and the amount of soft tissue in the buttocks, the previous chapters showed that sitting posture is also responsible for the size and direction of the external load on the buttocks.
The pressure-distribution qualities of the cushion were defined as being the ability to distribute the pressure across the buttocks in such a way that the pressure under the ischia tuberosities remains as low as possible. The highest pressures on the entire seating surface are always measured under the tuberosities.
A low pressure not only provides a comfortable feeling but is also one of the most important factors in preventing decubitus in wheelchair-users.
Decubitus arises as a result of long-term distortion of tissue which is brought about by external load alone. The combination of pressure and shear forces, i.e. friction forces, are viewed as being the most effective in this case.
Using results of several experiments the previous chapter showed that every pair of buttocks has its own unique pressure-distribution capacity which is optimised by minimising changes to their shape when a load is applied.

In order to be able to select the right kind of cushion for a wheelchair-user and to use it effectively, comparable product information is required for indicating the pressure-distribution ability of a cushion or cushion system. This however is a complicated process, since there are a diverse range of parameters which come into play.

Accurately defining and measuring the pressure-distribution qualities of a wheelchair-cushion under laboratory conditions has, thus far, unlike the many clinical tests which have been carried out, only been performed to a limited extent.
Measuring the quality of pressure-distribution under laboratory conditions has so far been done by loading the cushion statically with a rigid wooden test dummy. The so-called interface pressure, the pressure between the test body and the cushion, is measured at its deepest point and this is frequently done using an Oxford Pressure Monitor (OPM), or similar apparatus (Handikappinstitutet, 1987; Weustink, 1989). The wooden test dummy has a shape which is more or less derived from the actual shape of a pair of seated human buttocks. Though the load is realistic in these tests, it is usually on the low side at 500 N. Circular shaped test- or indentation dummies have also

been used (Cochran, 1980). Assessment criteria for pressure-distribution quality in relation to user groups, which have been defined, have not been developed. Cochran (1980) uses a 'performance factor' in which the pressure-distribution quality is compared to that of a standard foam cushion.
In addition to pressure-distribution Cochran's study measures other attributes such as moisture and heat regulation. This also formed part of the other two studies which are quoted before. The results however have not been used to classify cushions according to their quality.

In regular tests with respect to cushion quality, carried out under clinical conditions, attention tends to be focused primarily on pressure-distribution. Pressure-distribution is usually measured using small groups of disabled and able-bodied test subjects. Measurements are taken of the interface pressure directly under the ischial tuberosities. For each test subject the measurements are repeated a number of times on the same cushion. Each test may reveal large variations since not all the parameters and conditions referred to previously can be kept constant. One major problem is the positioning of the test cell or cells under the ischia tuberosities. The mean maximum pressure taken from all the test readings is considered as being the definitive test result for each test subject. The mean of the total mean maximum pressures taken from all test subjects is considered along with the standard deviation to provide the definitive result for the cushion. Large differences in maximum pressure on the ischia tuberosities can occur amongst disabled test subjects using the same cushion. Engel (1986) measured a distribution range of 90 to 310 mmHg (see figure 1-14). Conclusions which might be applied for clinical purposes are seldom reached in these studies.

Bar's clinical study, described in section 2.3.4, links the average pressure taken under the ischial tuberosities over a period of two hours with the reaction of the skin measured on completion of the test. Three types of skin tissue reaction were identified. The mean observed pressures were linked to these reactions.

In another clinical study Garber (1982) draws a link between the results and the structure of the body. She defines 'slim', 'normal' and 'thickset' as being 10% above or below the 'ideal' weight. The ideal weight is related to height, weight, age and sex. Using this approach it would appear that slim people more frequently show higher pressures under the ischial tuberosities than 'normal' or 'thickset' people. If this approach is adopted, the question remains as to whether sufficient differentiation is made in the amount of soft tissue which, in relation to the sitting weight, may effect the pressure-distribution results.

Except in cases where it is the specific intention (e.g. Hobson 1992) the results of pressure-distribution are not related to sitting posture. Neither are the specifications of the support structure given (e.g. the sagging of a sling seat) and as such cannot have been included in the analyses.

As regards the results of clinical evaluations the question remains as to whether an understanding can be gained of the pressure-distribution for a group of disabled test subjects when using a number of different cushions, or whether the pressure-distribution quality of a cushion can be established by using a number of disabled and/or a number of able-bodied test subjects.

In assessing the quality of pressure-distribution the interface-pressure readings are nearly always related to the size of the capillary pressure. One should aim for an interface pressure of below 35 mmHg, since arterial capillary blood pressure is set at around this same level. It is now an established fact that no single cushion meets this criterion (e.g. Jay 1984) and that the pressure measured internally is much greater than the interface pressure.
Bar's study (1988) showed that the load of the buttocks during sitting is of an extremely dynamic nature. Section 2.3 analyses whether or not this dynamic element might be the reason why so few people suffer from decubitus instead of so many, despite the fact that the internal pressure is considerably higher than the capillary pressure in the vascular system.

This chapter describes the development of a measuring system with which the pressure-distribution quality of a cushion can be established under laboratory conditions in the context of a comparative survey. This measuring system makes use of an artificial pair of buttocks which has the shape, structure and dimensions of their human equivalent. Inside the artificial buttocks 19 pressure sensors are positioned at strategic places.
A method will be developed whereby the pressure-distribution quality of a cushion is expressed using one single index, based on the elements essential to pressure-distribution during the sitting process and on the quality of the pressure-distribution.

4.1 Designing the measuring instrument: general principles

In setting up the comparative survey of wheelchair-cushions one of the pre-conditions was that pressure-distribution should be measured under laboratory conditions as realistically as possible and incorporating a large measure of validity and reproducibility. The pressure-distribution quality of air-filled cushions, in particular, needs to be more accurately verified, since practical observations have revealed large differences for these cushions.
One of the first considerations was how to replace the wooden test dummy in

use at the time (Weustink 1989) by a more realistic one which replicated not only the external shape and size of a human pair of buttocks but also its internal structure. Soft tissue in the buttocks after all works as a pressure-distribution medium and is deformable. The greater the mass of soft tissue, the lower the interface pressure observed. Not only is the bulk of soft tissue under ischial tuberosities important here, but also the expanse of the surface under load.

The test dummy should therefore consist of a hard structure resembling the pelvis, surrounded by a soft structure resembling tissue and contained within a 'skin'. The test dummy's dimensions should correspond to a relevant type or types identified in the user population.
The pressure-distribution results as such seem to depend on individual characteristics.
Initially three types of buttocks were considered: a male pair of buttocks, a female pair and a pair of buttocks typical to a wheelchair-user with muscle tissue showing atrophy.
Since no prior experience was available for making and carrying out tests with such a dummy - hereafter referred to as the 'test buttocks' -, it seemed pragmatic to begin with just one version. For this reason it was decided to make a prototype which incorporated the critical dimensions common to a 'male' pair of buttocks. In practice this meant opting for a relatively low pressure-distribution capacity in respect to the buttocks themselves and therefore for a critical validation of the pressure-distribution capacity of the cushion. Although the original design concept included a three dimensional 'abstraction' of the pelvis, the final choice, made on the basis of practical considerations, fell instead on an artificial male pelvis with two attachable thighs, available commercially primarily for educational purposes. This model provides a true-to-life representation of the pelvis.
Opting to use the critical dimensions of a male pair of buttocks in turn means opting for a relatively low amount of soft tissue - about 15 mm under the ischial tuberosities and a relatively small surface in combination with a relatively large weight. The amount of soft tissue under the ischial tuberosities was made in consultation with a physiotherapist on the understanding that the dimensions should be critical. The final version of this uses a narrow hip width of 34 cm and a load of 600 N. This is the average sitting weight of a person weighing 75 kilos.
As a means of comparison table 4-1 lists some relevant anthropometric data taken from the population at large in the Netherlands

sitting dimensions	male average	SD	women average	SD
dist. buttock-back of the knee [mm]	518	30	494	32
hip width [mm]	375	20	395	34
body weight [kg]	76	10	65	10

Table 4-1 : Anthropometric data of adult male and female population in the Netherlands (Dined-table, Molenbroek en Dirken, 1986)

Women tend to have wider hips and show greater standard deviations. The choice of hip size lies between a P 5 and P 50 male whilst the body weight is equivalent to a P 50 male. This, together with the small thickness of soft mass under the ischial tuberosities, means that the test dummy is 'critical'.

Commercially available cushions are not usually manufactured with a specific buttock size or shape in mind, or for that matter a specific weight. In adopting a 'critical' male pair of buttocks as the basis for the test dummy, a clear and concise range of pressure-distribution capacities for the cushions will provide a sound basis for a comparative survey.
Where commercially available cushions do take the body weight and the shape of the buttocks into account, a suitable cushion can be selected for investigation. Results might demonstrate that such a cushion has positive advantages over a cushion which has no specific user in mind. Therapists are likely to choose a cushion which corresponds most closely with the manufacturers' specifications. This provides the solid platform from which a comparative survey can be carried out.

Another point to consider is whether the type of load is dynamic or static. Bar (1988) and others have conclusively demonstrated that dynamic load is present in wheelchair situations. The dynamics are initiated by movements, which are made by the upper half of the body in relation to the lower half of the body, when a number of different activities are carried out . This means that the centre of mass of the upper half of the body is displaced. This can take place in two different ways: symmetrically in relation to the ischial tuberosities, or asymmetrically. When the upper half of the body is moved forwards, the load placed on the ischial tuberosities is reduced. A sidewards movement means that the load becomes asymmetric, causing an increase in load on one side and a decrease on the other. The mobility of the lumbar spinal cord in the frontal plane and the way in which the upper half of the body is supported by the arms are important elements in this. It is quite plausible in practice that one cushion will react better than another to this change of load and that this can be considered as one method of determining cushion quality. Symmetric pressure-distribution, however, remains the basis for the pressure-distribution

and as such the primary basis on which the qualitative comparison is made under laboratory conditions.
The first investigation will discuss the effects which the static load of the test buttocks has on the cushion. In a second, follow-up investigation the effects of another version of the test buttocks will be measured and the effects of static asymmetric load on the pressure-distribution as a way of assessing dynamic load during sitting.

As regards the choice of test instrument the idea was soon conceived, partly on the basis of Le's publication (1984), to place pressure sensors *inside* instead of on the *underside* of the test dummy. Using this option it was anticipated that air-filled cushions could be tested more accurately than by the conventional method. This option does in fact have a number of advantages: a model can be formulated of how the buttocks behave *inside*; how the external load is transmitted and which pressures eventually occur in different places; above all however, this approach gives us the possibility of comparing internal results with 'normal' interface values and to see what effect the test cells might have on the test results. The effects are thought to be substantial, but this fact has as such never been substantiated.
In addition to practical and financial considerations such as duplicating the shape and weight of the ISO wheelchair test dummy, the specifications for the test buttocks' *first* prototype include the requirement for visible and possibly quantifiable 'deformability'. Internal deformability, resulting from pressure and shear forces, is after all considered to be the greatest single cause of decubitus (e.g. Bennett 1979) and it would be highly interesting to make this both visible and, if possible, quantifiable. This requirement, however, soon appeared to be unfeasible. A transparent silicone material with sufficient softness could not be found anywhere and the term 'deformability' appeared difficult to define objectively. Furthermore a silicone mass is impermeable to x-rays, thus eliminating this possibility. A large number of test readings were made on the first prototype with existing as well as experimental cushions in order to understand both the principle of the test instrument and the pressure-distribution performance of cushions. These experiences are set down in a programme of specifications, used for a definitive version of the test buttocks. The ISO dummy was eventually rejected, appearing to be too 'angular' in relation to reality, once it had been compared with a cast of a male subject's buttocks free of load. Using the ISO dummy the load appeared not to be sufficiently reproducible on account of the effects of the cushion on the 'sitting posture'. A dynamometer was eventually chosen to apply this load. This instrument is capable of measuring a constant fixed load on an object. Using this method the pressure readings can be separated from the effects of posture and analyses of posture. The assumption made here is that a correct sitting posture causes no shear force in the contact plane between the seat and the buttocks. In this way the cushion can be subjected to a vertical load in one test

position without paying concessions to reality. This is an important basis in facilitating the reproducibility and comparison of test results. The influence which the cushion has on shear forces - which implies an incorrect sitting posture - can be measured as a separate characteristic.

4.1.1 A description of the test buttocks

The test buttocks represent that part of the human behind in the sitting posture which comes into contact with the sitting support. The test buttocks consist of a hard structure of male pelvis and thighs, Mark 3B, surrounded by a soft structure of silicone mass, enclosed by a synthetic skin comprising a somewhat stiffer silicone material reinforced by a tricot fabric. The knee joints were removed from the thigh bones; see photo 5. The silicone mass is of the Dow - Corning make, Base Q3-3486, diluted with an amount of silicone oil. Samples were made to achieve the correct softness and were compared by a physiotherapist and a surgeon with non-tensile muscle tissue. Simple indentation tests were carried out on these samples and likewise on muscle tissue.
The overall weight of the test buttocks, including the aluminium attachment plate came to 25 kilos and they measure 50 cm (length) x 34 cm (width) and 22 cm (height). The shape and size of the test buttocks were taken from an impression of a male test subject weighing 75 kilos with a sitting weight of 62 kilos and a hip width, in the seated position, of 36 cm. The shape of the test buttocks was achieved by fitting a cone, which had a 110 mm and 230 mm diameter at a height of 355 mm at its widest, with a circular head, by smoothing down the cone along its length and dividing this plane symmetrically in two. By attaching the two tapered planes together one can achieve the shape of the test buttocks (Pollmann 1993). The procedure is shown in figure 4-1. During the fabrication of the test buttocks a great deal of attention was given to the reproducibility of the test instrument.

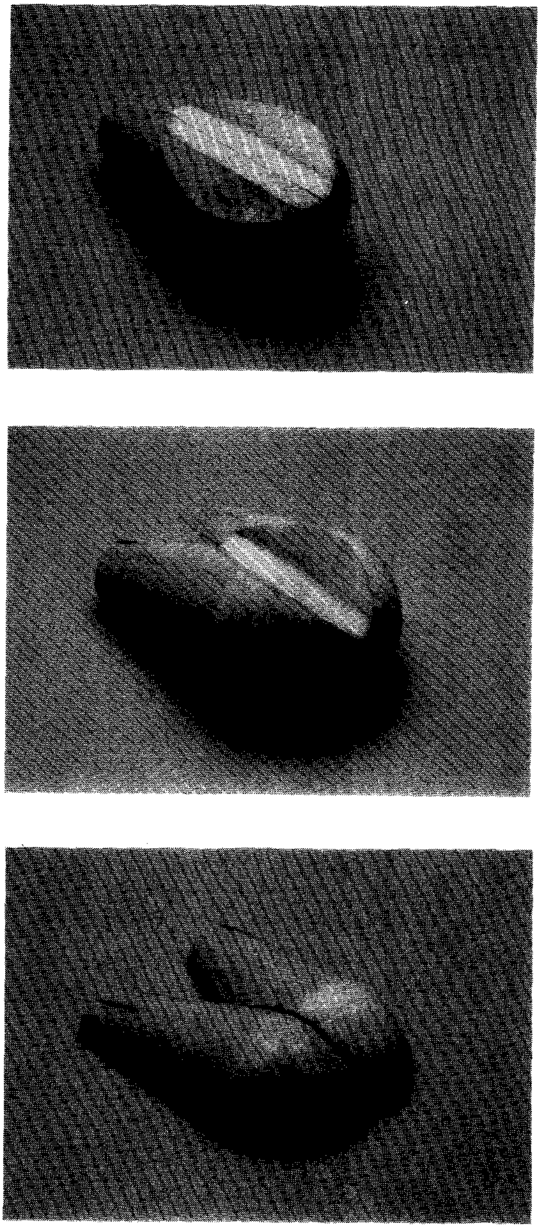


Figure 4-1 : Geometrical formation of the test buttocks' structure.

Illustrative drawings of the test buttocks are included in appendix 1.
A total of 19 pressure sensors were applied at strategic places in the test buttocks: 9 on the bone, 9 directly underneath these bone sensors on the inside

of the skin and one 'floating' pressure sensor. The positioning of the pressure sensors was determined by a number of factors. The ischial tuberosities and the sacrum would appear to be the most vulnerable spots during sitting. Decubitus predominantly forms in this region. Corresponding bone and skin sensors were placed to enable an analysis of the internal transmission of forces and to enable a comparison with Le's results (1984). Two sensors were placed symmetrically opposite to each other as control parameters. The 'floating' sensor complements the cross-section. The fact that full symmetry of the sensors was not realised resulted from financial considerations only. Figure 4-2 shows the positioning and coding of the pressure sensors.

The pressure sensors on the bone were 'Kyowa' make sensors, type PS-2KB, and type PS-2KA for the skin sensors and the 'floating' sensor. Their diameter was 6 mm. Their sensitivity was 20 N/cm^2 , which for the sensor means a sensitivity of 5.6 N. Output voltage was 1mV/V. The hysteresis and non-linearity amount to 1%. The sensors are controlled by means of an alternating current. By means of synchronous detection each of the sensors is linked up to a PC-AT, using a Hewlett-Packard 75000 data-acquisition system with a frequency of 2 Hz for all 19 sensors.

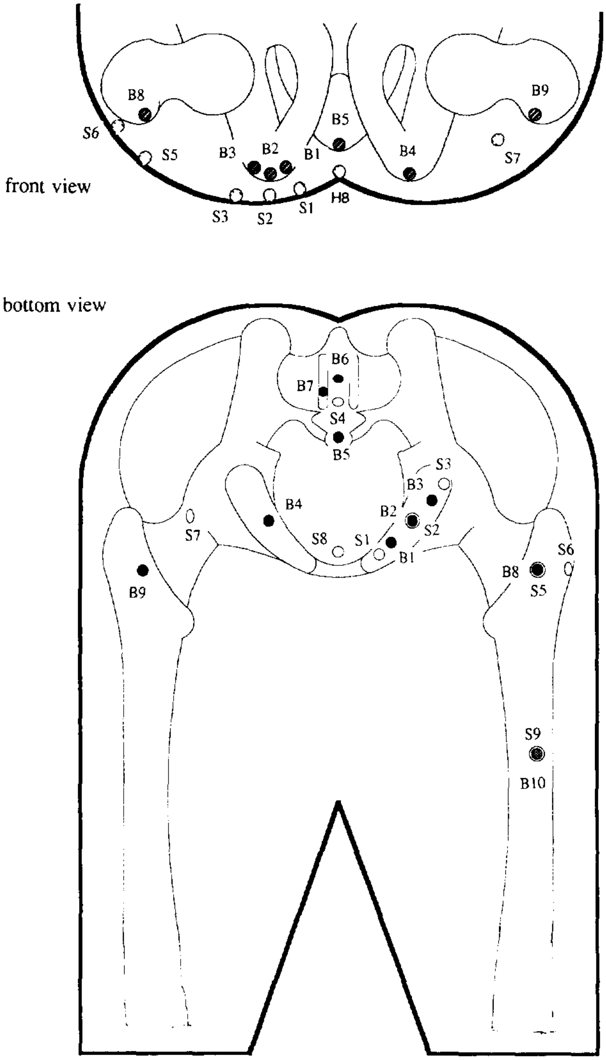
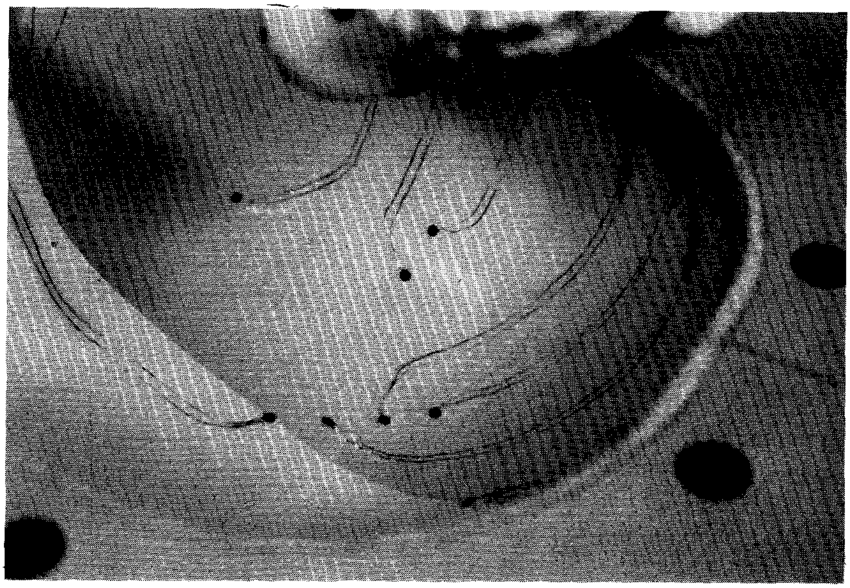
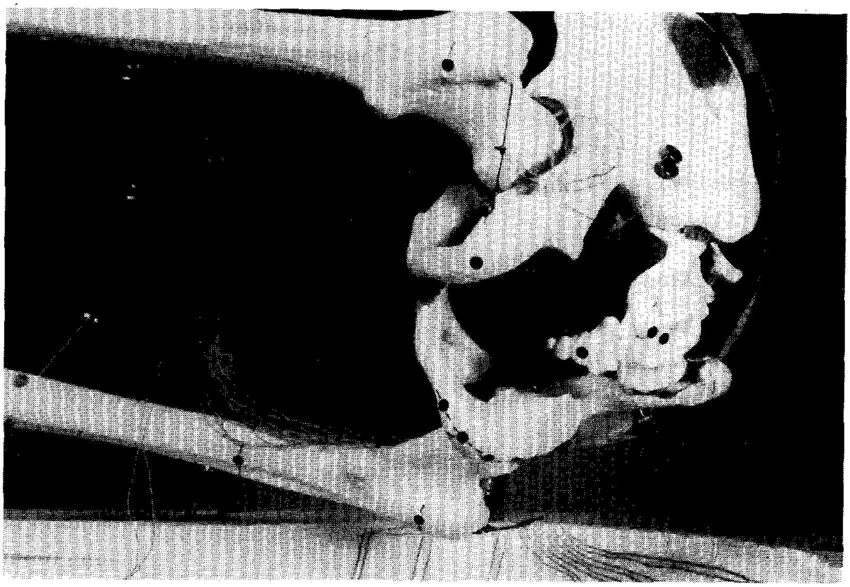


Figure 4-2 : Positioning en coding of pressure sensors in the test buttocks, 0 and 0 bone sensors, 0 skin sensors.

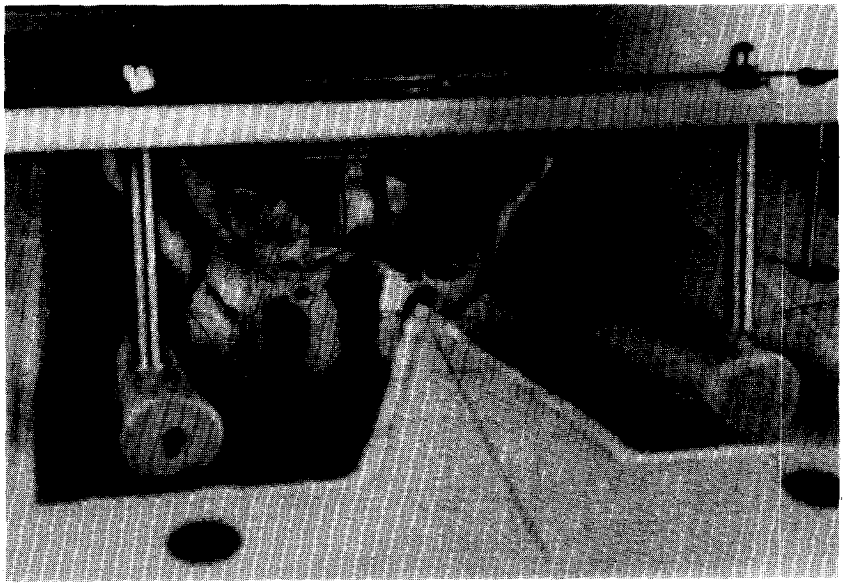
Photographs 3, 4 and 5 show the test buttocks before the addition of the silicone mass.



Photograph 3 : Positioning of skin sensors.



Photograph 4 : Positioning of bone sensors on the pelvis.



Photograph 5 : Positioning of the pelvis in the casting mould.

The test buttocks were suspended on a Zwick dynamometer which could be adjusted beforehand to provide a constant load. The cushion was subjected to a force of 600 N. This force is applied at a point located 15 cm on the rear of the test buttocks. At this point the test buttocks were suspended by means of a hinge pin positioned in a transversal direction. In this manner the test buttocks were able to swivel in a longitudinal direction on this pin and 'nestle' into the cushion. Using a pressure cylinder a force of 61.5 N was exerted on the thighs at a distance of 10 cm from the hinge pin. This value was arrived at by means of calibration using a test subject with comparable shape and sitting weight and by comparing the angle of inclination of the thighs with each other as a result of indentation. A drawing of the suspension construction is shown in figure 4-3.

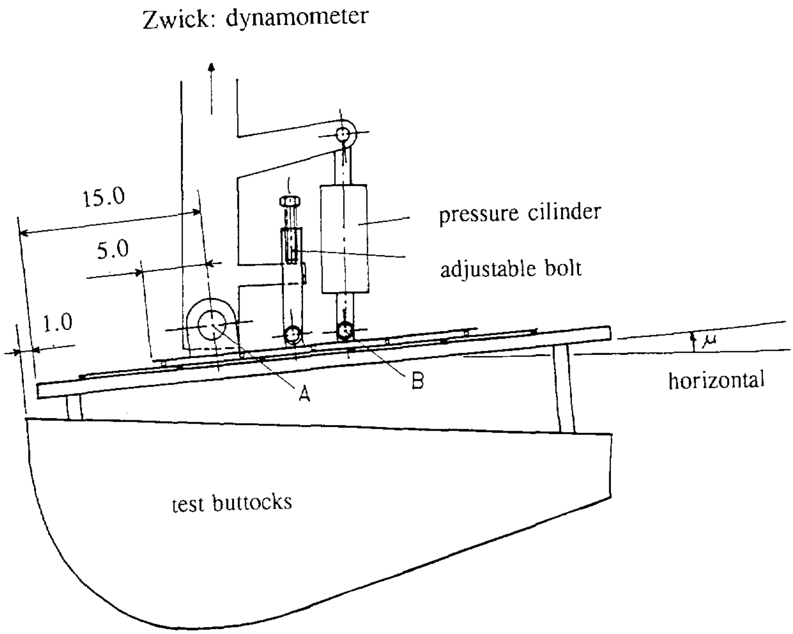


Figure 4-3 : Suspension construction of the test buttocks in the dynamometer (cm).

Those cushions without a support structure of their own were placed on a 'standardly' elevated sling seat construction. This sagged by 4 cm when subjected to a load. The sling seat construction was located on a platform which had a degree of freedom in the longitudinal direction of the test buttocks. This meant that the cushion could be easily affixed to the test buttocks without introducing unwanted loads. Cushions incorporating their own support structure were placed directly on the platform according to the way in which the support structure needs to be loaded.

4.1.2 Test procedure

Before commencing testing, a control test was carried out on a flat board using a so-called pre-load cushion, consisting of a 100 mm thick piece of DRAKA 9018 foam with a specific mass of 35 kg/m^3. The results were compared with previous results. A large number of these control tests were subsequently carried out and used to gain an insight into the accuracy of the test buttocks. See also section 4.1.5.

As a general rule a cushion was placed underneath the test buttocks according to the specifications of the manufacturer. Cushions incorporating their own support structure are more sensitive to positioning than cushions without this support structure. The position of the test buttocks on the cushion was selected on the basis of its evident intended use. Photograph 6 gives an indication of the testing apparatus.

A cushion test began with a double cycle in which a load was first applied and then removed. The test then continued with the cushion being subjected to a load for 2 minutes. During the test procedure the test signal of the pressure sensors was reset to zero immediately before the load was applied. The pressure increase in the pressure sensors was recorded for the whole of the load cycle. The values recorded after 60 seconds provided the basis for the definitive pressure-distribution results and were used for determining the pressure-distribution quality. It was shown that after 60 seconds no noteworthy changes in readings occurred other than those which resulted from the constant regulation of the load performed by the 'Zwick'. Indentation was measured both when the load was applied and when the load was removed.

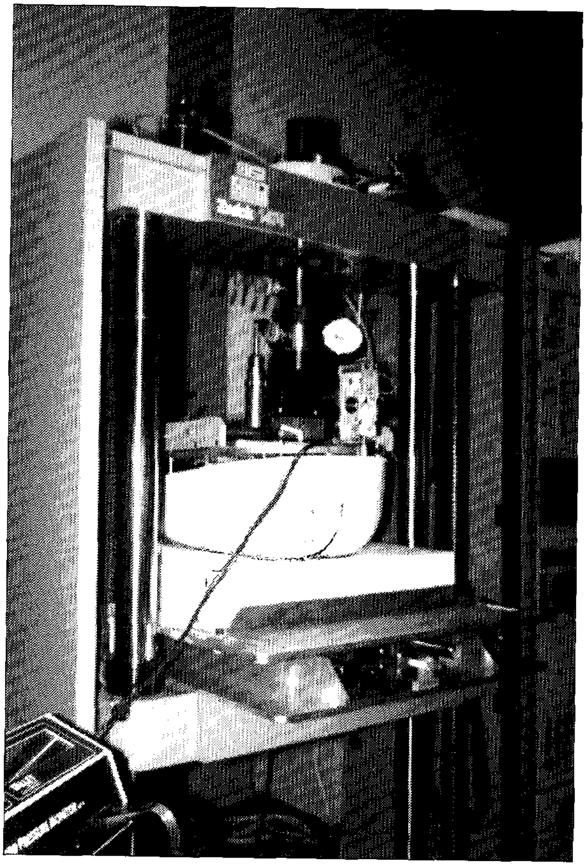
4.1.3 Validation of the test buttocks

In order to find out to what extent the results achieved with the test buttocks equate with real-life results, a series of comparative tests were carried out on a flat board, using the so-called pre-load cushion, the 100 mm thick DRAKA foam cushion. These tests consisted of measuring the interface pressure by means of the OPM on the cushion. Pressure readings from the tests buttocks were compared with the readings taken using the same cushion and using the test subject who provided the 'casting' for the test buttocks.
This comparison provides a practical validation of the test buttocks.

The basis for this comparison is formed by the foam on a horizontal, hard and flat support. Two tests were carried out on the test subjects:

- an active, upright posture without the use of a backrest:
  i.e. a normal lordosis of the lumbar spinal column, the pelvis adopting a position which fits this posture;
- a slumped sitting posture without the use of a backrest:
  i.e with a kyphosis of the lumbar spinal column with the pelvis tilted backwards.

The OPM's test cell was placed directly under the ischial tuberosities of the test buttocks and those of the test subject. The results of this exercise are presented in table 4-2. The table also includes the results of the tests carried out on 'Demo F' cushion, used as a point of reference in the cushion survey



Photograph 6 : The testing apparatus.

		sitting weight/load	pressure	
TS active upright sitting posture	OPM	622 N	61 mmHg	*
TS slumped sitting posture	OPM	622 N	105 mmHg	*
Test buttocks	OPM	600 N	85 mmHg	*
Test buttocks	OPM	600 N	98 mmHg	**
Test buttocks	pressure sensor S2	600 N	144 mmHg	**
Test buttocks	pressure sensor B2	600 N	166 mmHg	**

* Draka 9018 100 mm on flat board without cover.
** 'Demo F': Draka 9018 100 mm on flat board with loose-fitting stretch cover.

Table 4-2 : The interface pressure of test buttocks and test subject (TS) and the pressure in the test buttocks of skin and bone sensors directly under the tuberosities.

The results reveal a number of points. Firstly, the magnitude of interface pressures for the test buttocks, 85 and 98 mmHg, and those taken for the test subject, 61 and 105 mmHg. It is interesting to note that an active sitting posture with tensed-up muscles reveals a lower interface pressure than for a relaxed posture where the pelvis is tilted backwards. Tensed-up muscles are more 'robust' than relaxed muscles. The weight of the upper half of the body is transmitted via the spinal column through the pelvis to both ischial tuberosities. More robust buttock muscles evidently spread this transmitted force outwards more effectively than do more flaccid buttock muscles. This proves the point that the buttocks possess a pressure-distribution capacity of their own. The test buttocks reveal an interface pressure with values which lie between those recorded for the test subject. Since pressure-distribution is 'individual' by nature and depends on the shape, dimensions and composition of the buttocks, this conclusion alone provides us with enough evidence to carry out a comparative survey and assessment of cushions on the basis of the criteria selected. Since the test subject has a 'critical' pair of buttocks in relation to the population, the test instrument meets the precondition that the tests need to be carried out in a 'critical' fashion.
The second interesting aspect of the results is in the comparison of the test buttocks' interface pressure with those internally. The results taken for the test buttocks correspond to the findings of Le (1984), which contend that the pressure in the neighbourhood of the protruding areas increases and is considerably higher than external pressures. The skin sensor S2 under the ischial tuberosity shows a lower pressure reading (144 mmHg) than the bone

sensor (166 mmHg). This latter value is almost twice as high as the interface pressure measured between the test buttocks and the cushion (85 mmHg). Section 4.4 will analyze this in more detail.

4.1.4 Analysis of test results for the Draka 9018 100 mm foam

Table 4-3 shows the test results for all pressure sensors on the test buttocks for the Draka 9018 100 mm foam on a flat board.

			mmHg
S1	skin sensor	tuberosity - front	63
S2		tuberosity - right	149
S3		tuberosity - rear	101
S4		coccyx	-4
S5		top of thigh - under	46
S6		top of thigh - side	9
S7	floating	betw. tuber. and top of thigh - left	67
S8		cleft in buttocks	18
S9		thigh - middle	34
B1	bone sensor	tuberosity - front	104
B2		tuberosity - right	164
B3		tuberosity - rear	134
B4		tuberosity - left	169
B5		coccyx - low	53
B6		coccyx - high	-18
B7		coccyx - middle/outer	16
B8		top of femur - right	58
B9		top of femur - left	62
B10		thigh - middle	50
ZWICK	load during test registration in N		594.9

Table 4-3 : Test results on Demo F cushion: 100 mm DRAKA 9018 foam on flat board with thin stretch cover (mmHg).

Closer study of these results will lead to the following observations:
Two test cell positions in the test buttocks are located symmetrically; B2 and B4 (those cells directly under both tuberosities), and B8 and B9 (at the top of each thigh). Table 4-4 once more lists these results.

right bonesensors	B8	B2	B4	B9	left bonesensors
	58	164	169	62	mmHg

Table 4-4 : Test readings of the symmetrically placed pressure sensors of the Demo F cushion: 100 mm Draka 9018 foam on flat board.

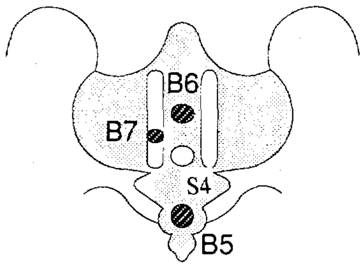
A range of no more than 5 mmHg separates the respective symmetrical results.
A second observation is the difference in the skin and the bone readings: bone readings, in all cases, are higher.
The results are presented against each other in table 4-5.

	B10	B8	B3	B2	B1	bone sensors
	S9	S5	S3	S2	S1	skin sensors
B:	50	58	134	164	104	mmHg
S:	34	46	101	149	63	mmHg
difference	16	12	33	15	41	mmHg

Table 4-5 : The difference in test readings between skin sensors and bone sensors of the Demo F cushion: 100 mm DRAKA 9018 foam on flat board.

The difference between skin readings and bone readings has already been shown by Le (1984) in his experiments using pigs.
The difference is determined by the thickness of the intermediate layer and the shape of the bone.
The test buttocks reveal that, the greater the thickness of the silicone mass, the greater the pressure difference is, at any rate for the bone protrusions, B3, B2 and B1. An indication for the thickness of the intermediate layer can be seen in figure 4-2.
The greatest pressure is recorded here against the side of the bone. When the bone has a larger surface area, this difference becomes smaller; compare the test readings of B10 and B8 cells, the middle thigh cell and the top of the thigh cell respectively, with the skin cells S9 and S5.

Finally, a few remarks about the coccyx and the cleft of the buttocks.
Figure 4-4 represents a bottom view of the location of the coccyx sensors with the test results.
The test results show that 'negative' pressures can occur. This means that tissue is pulled instead of pushed. In view of the fact that the pelvis, under the influence of the weight of the upper half of the body, sinks, as it were, into the softer parts of the buttocks, it is quite plausible that, where a certain friction between the skin and the cushion occurs, small tractive forces operate on the coccyx.



B6 = -18 mmHg
B7 = 16 mmHg
S4 = -4 mmHg
B5 = 53 mmHg

Figure 4-4 : Coccyx readings on the Demo F cushion: 100 mm DRAKA 9018 foam on flat board (mmHg).

For many cushions the H4, B6 and B7 values are negative. In general these readings are low.

4.1.5 Accuracy of testing on the test buttocks

In the test procedure, before the test cycle begins, the test buttocks are subjected a number of times to a load using the so-called pre-load cushion. This pre-load cushion consists of a 100 mm thick piece of DRAKA 9018 foam with a density of 35 kg/m^2 placed on a flat board.
When the pre-load cycle has been completed, a pressure test is carried out. The results are checked and taken down on paper.
From the beginning of the survey in June 1991 until July 1992 a total of 46 tests were carried out on the pre-load cushion. The mean results, plus the standard deviation (SD) for the whole of the period are presented in table 4-6.

			average	SD
S1	skin sensor	tuberosity - front	65.7	3.9
S2		tuberosity - right	146.3	4.5
S3		tuberosity - rear	93.0	2.5
S4		coccyx	-2.2	3.8
S5		top of thigh - under	42.7	3.7
S6		top of thigh - side	14.3	2.5
S7	floating	betw. tuber. and top of thigh-left	62.3	4.1
S8		cleft in buttocks	19.0	3.5
S9		thigh - middle	35.0	2.8
B1	bone sensor	tuberosity - front	117.8	10.2
B2		tuberosity - right	173.5	6.5
B3		tuberosity - rear	131.0	5.2
B4		tuberosity - left	176.8	14.7
B5		coccyx - low	49.1	4.6
B6		coccyx - high	-5.2	4.5
B7		coccyx - middle/outer	24.3	4.1
B8		top of femur - right	60.8	3.3
B9		top of femur - left	61.5	2.7
B10		thigh - middle	52.4	2.9
Zwick	load at moment of registration		599.1	5.2

Table 4-6 : Mean pressures in sensors with SD from 46 tests taken on the pre-load cushion during a period of 10 months (mmHg).

It is probable that the pre-load cushion, which was not fitted with a cover, showed an element of ageing over the period of 9 months during which it was in use. This is why the mean readings and the standard deviations have been calculated for periods of 3 and 4 months. The results are shown in table 4-7.

From this table it can be seen that the average pressures for almost every test-cell increase and that this increase is more marked between the second and third periods than between the first and second. On average the difference is 6.82 mmHg between the first and the third periods with large differences between B1 and B4 (19.4 and 21.7 mmHg respectively). It is assumed that the quality of the unprotected pre-load cushion deteriorated over a period of time. There are no indications that any changes took place in the condition of the testing instrument over the same period.

A comparison of the standard deviations for individual test-cells across the three periods shows that B4 has a much higher SD than for other cells. The result for this cell can be set against that of B2 which is symmetrically comparable. For unclear reasons the B4 sensor measures less accurately than the B2 sensor as well as other cells.

		3 months n = 12		3 months n = 19		4 months n = 15
sensor	mean	SD	mean	SD	gem.	SD
S1	63.0	3.2	65.3	3.1	68.4	3.8
S2	142.7	3.6	144.7	2.1	150.8	3.8
S3	92.5	2.7	92.2	2.5	94.1	2.1
S4	-2	4.8	-4.5	2.4	0.8	2.1
S5	40.7	1.5	40.9	2.5	46.3	3.6
S6	13.0	0.9	13.4	2.4	16.5	2.0
S7	60.3	2.4	61.2	4.1	65.5	3.4
S8	16.8	1.8	17.9	2.9	22.2	2.9
S9	33.3	1.6	34.1	2.6	37.2	2.6
B1	110.1	4.2	113.6	7.1	129.5	4.8
B2	168.1	4.0	171.3	4.3	180.5	4.1
B3	127.7	4.8	129.3	3.6	135.3	4.5
B4	168.6	10.0	171.9	13.0	190.3	10.2
B5	46.8	3.4	47.2	2.9	53.3	4.4
B6	-8.1	2.9	-6.7	3.2	-0.9	3.8
B7	22.5	3.0	24.0	3.8	26.3	4.5
B8	58.5	2.1	60.1	2.3	63.7	3.4
B9	59.2	1.5	60.9	2.0	64.0	2.0
B10	51.0	1.6	51.7	2.7	54.5	3.1
Zwick	601.5	(2.2)	599.3	(3.3)	596.8	(7.7)
mean		3.15		3.66		3.74
SD		2.02		2.54		1.80

Table 4-7 : Test results for pre-load cushion over periods of 3 and 4 months (mmHg, Zwick in N).

Altogether the cells show a standard deviation of 3.51 mmHg over the 3 and 4 monthly periods with a standard deviation of 2.21. These results can be considered to be fairly acceptable. For a mean pressure of 69.38 mmHg (SD = 55.8) across all cells during the whole period, this means a deviation of 5%. The significance of the accuracy of individual test sensors on the pressure-distribution quality - to be defined later - will be discussed in section 4.2.4.

4.2 Processing the test results

The results of the pressure tests can be presented in graph form, in order to gain a better insight into the pressure-distribution results. An example of this is shown in figure 4-5.

mmHg

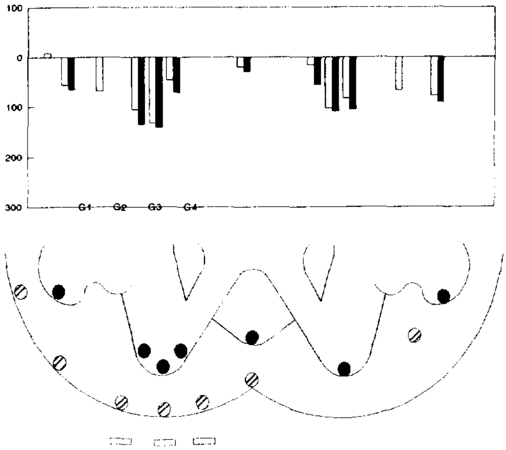


Figure 4-5 : Presentation of test results in graph form (mmHg, dark= bone sensors, light=skin sensors).

In order to compare and assess cushions properly, we need more than just a presentation in graph form. This can be done by registering pressure-distribution quality in numeric form, preferably on a scale of 0 to 100.
In order to establish an index, it is necessary to take a closer look at the cushion's intended function and therefore at the principle of pressure-distribution.

The pressure-distribution performance of a good cushion is determined by its ability to reduce load on the area around the ischial tuberosities. It therefore follows that the rest of the surrounding area will be subjected to increased loads.
The *degree* to which this is achieved might provide an indication of the *scale* of the pressure-distribution.
The *way* in which this 'pressure-distribution is brought about might say something about the *quality* of the pressure-distribution. Large differences in pressure should be avoided whenever possible, as already stated in section 2.3.1. Pressure therefore needs to be distributed as evenly as possible.

The principle of pressure-distribution can be found in the relationship between the load to which the area around the ischial tuberosities is subjected and the load to which the rest of the surface is subjected. Since the amount of load is known, the principle of pressure-distribution can be considered to be the percentage of load which the sitting surface - minus the small area around the tuberosities - absorbs.

The even distribution of pressure is linked to the magnitude of pressure differences, sometimes referred to as the pressure gradient, defined in terms of difference in pressure over a particular distance.
The following section discusses these two concepts - pressure-distribution (PD) and equality (EF) - in more detail. These will be converted into a definitive formula, which will indicate the pressure-distribution quality (PDQ) of a cushion.

4.2.1 Definition of pressure-distribution (PD)

Pressure-distribution can be defined as being the percentage of the total load which is exerted on the buttocks excepting the area around the tuberosities.
The following example is given to elucidate this:
Suppose the total load on the sitting surface is measured at 600 N, of which 200 N is taken up by the small areas in the region of the tuberosities (not yet defined), then the rest of surface of the buttocks takes up 400 N. Using the following formula the pressure-distribution can be calculated as being:

$$PD = \frac{400}{600} \times 100 = 66\%$$

This approach enables pressure-distribution to be expressed in numerical terms, i.e. on a scale of 0 to 100. The higher the number, the better the pressure-distribution quality of the cushion, and the lower the load exerted on the tuberosities.

By defining the surface area around the tuberosities, the load on the tuberosities can, in theory, be calculated using the test buttocks' results. Since the total load is measured at 600 N a PD value can be determined.

Three sensors, B1, B2 and B3 were placed on one of the test buttocks' tuberosities plus a further 3, S1, S2 and S3 directly underneath on the inside of the 'skin'. The most obvious thing to do is to ascribe the pressure readings measured for these cells to a certain representative surface. By doing this it is possible to measure the pressure exerted in N.

A decision was taken to use the mean pressure values between S1 and B1, S2 and B2, and S3 and B3 for this calculation. The distance between skin sensors was 3.0 cm. This can be viewed as the operational area around each sensor, making for a circle of 9 cm diameter around the sensors with a surface area of 65 cm^2. In order to give more weighting to the central tuberosity sensor, its operational area was enlarged to 3.5 cm with a surface area of in the region of

10 cm^2. The mean values of the H1, B1, H3 and B3 sensors were designated a surface area of 65 - 10 = 55 cm^2.

Figure 4-6 shows that the circles almost touch each other in the anal cleft region. These areas are considered the regions most vulnerable to the development of decubitus. O_3 is the maximum projected buttock surface area which can be exerted to load by a cushion. The extent, to which a cushion will use this surface area, can be seen in the readings which are given off by the tuberosity sensors. The extent of the surface under load is not relevant for the pressure-distribution (PD), as defined, since it is not included in the formula.

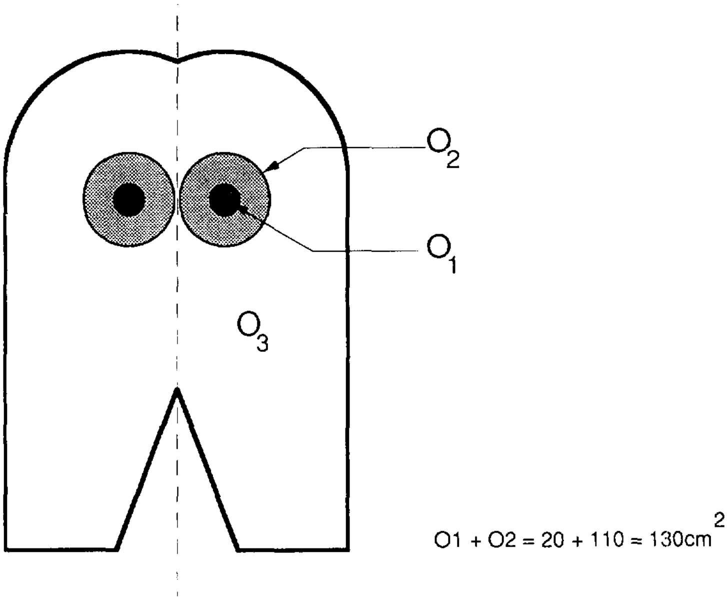


Figure 4-6 : Area defined around the tuberosities in order to calculate load.

In order to control the levels of symmetry and, in turn, to be able to determine the asymmetry of the pressure-distribution, both tuberosities were fitted with pressure sensors, B2 and B4.
Any differences between the left and the right-hand sides could be calculated by the relationship between B4 and B2. The revised formula for measuring PD is now as follows

The load p on O_1 is:

$$p = 20 \times 0{,}25\,(B2 + S2)\,(1 + B4/B2) \times 0{,}0133\ N$$

20 represents the surface area in cm^2, B2 etc. is given in mmHg and 0.0133 is the conversion factor from mmHg to N.

The load q on O_2 is:

$$q = 110 \times 0{,}125\,(B1 + B3 + S1 + S3)\,(1 + B4/B2) \times 0{,}0133\ N$$

The figures for B1,S1,B3 and S3 have not been corrected for a slight inclined position at the tubera.
This enables us to calculate PD using the formula:

$$PD = \frac{600 - (p + q)}{600} \times 100 = \%$$

The calculation of the PD shown here uses the example of the Demo F cushion. Demo F gave the following test results:

S1 = 63 mmHg	B1 = 104 mmHg	
S2 = 149 mmHg	B2 = 164 mmHg	B4 = 169 mmHg
S3 = 101 mmHg	B3 = 134 mmHg	

This enables the loads p and q, exerted on O_1 and O_2 respectively, to be calculated:

p = 42.26 N q = 149.27 N p + q = 191.53 N

Pressure-distribution PD is expressed as the percentage of the load (600 N) which is taken up, not by O_1 and O_2, but by O_3:

PD = { (600 - 191.53) / 600 } * 100 = 68.1 %

The decision to adopt a diameter of 9 cm around the area of the tuberosity is based on the area's susceptibility to decubitus. This is one of the reasons why such a relatively large number of sensors were placed in this region.
A larger or smaller diameter, i.e 120 cm^2 or 140 cm^2· may give slightly different results, but in principle this approach of defining pressure-distribution remains the same. A surface area of 120 cm^2 (15 + 105) in the above example would have given a PD result of 70.97 and for a surface area of 140 cm^2 (25 + 115) : 65.18.

4.2.2 Definition of pressure-distribution quality (PDQ)

The quality of pressure-distribution is determined by the way in which pressure-distribution in a cushion is achieved. The smaller the pressure gradient, i.e. the smaller the pressure difference over a pre-defined distance, the higher the pressure-distribution quality. This was discussed in detail in section 2.3.1. The quality of pressure-distribution might be expressed as a slight 'uprating' of the recorded PD when the pressure differences are small, or as a slight 'downrating' when the differences are large. This is particularly the case for differences in pressure in a cross-section across the tuberosities.

In order to be able to quantify the size and quality of pressure-distribution of a cushion as one single value, these differences in pressure should, using a factor, therefore be incorporated into a formula in such a way that the effect just mentioned occurs to an extent which can be defined.

Suppose that the average of the pressure variations at different, as yet undefined, positions brings about an equality factor (EF) which lies somewhere between the values of 0.700 and 0.900, then the product of PD * EF, expressed as a percentage of 80 will correspond to this concept.

The formula for pressure-distribution quality (PDQ) is now the following:

$$PDQ = \frac{EF \times PD}{0,8}$$

The size and quality of pressure-distribution can be expressed using this formula on a scale from 0 to 100.

The number '80' in this formula is arrived at by taking the rounded-up maximum of EF * PD, when EF = 0.9000 and the PD = 90%.
In the cushion survey (n=48) the maximum recorded PD is 85%. This percentage as the maximum obtainable is rounded up to 90. The formula for the EF has been chosen on the basis that 0.900 appears to be the highest maximum obtainable in the survey, whilst 0.700 appears to be the minimum. The maximum product of both maximums is therefore 81, which rounded down is 80. By expressing the result obtained from the product of PD * EF as a percentage of 80 a figure can be found on a scale of 0 to 100.

An example may explain the effect of the EF values in the PDQ formula:

Suppose for cushions A, B en C the pressure-distribution (PD) is the same (PD = 70%).
for cushion A the EF = 0.700 ,
for cushion B the EF = 0.800 and
for cushion C the EF = 0.900.

The PDQ of the three cushions is now:

$$Cushion\ A:\ PDQ = \frac{0{,}70 \times 70}{0{,}8} = 61$$

$$Cushion\ B:\ PDQ = \frac{0{,}80 \times 70}{0{,}8} = 70$$

$$Cushion\ C:\ PDQ = \frac{0{,}90 \times 70}{0{,}8} = 79$$

The result is that cushion A was downrated by 9 points for its PDQ compared to the original PD value and that Cushion C, as a result of better equality in pressure-distribution was uprated by 9 points for its PDQ compared to its original PD.
The effect of the quality of pressure-distribution on the amount of pressure-distribution is somewhere in the region of a maximum of 9/70 or 13%.
This influence was thought to be acceptable.

In this way the product of EF * PD, expressed as a percentage of 80, denotes a quality number on a scale of 0 to 100.
It matches the amount of pressure-distribution with the way in which it brought about, that is, the degree of equality.
This formula - and the preconditions - were eventually chosen as the basis for expressing the pressure-distribution quality of a cushion.
The way, in which pressure differences are translated into the above-stated factor between the values of 0.700 and 0.900, presents a special problem. The formula for the EF is developed and elaborated upon in the following section.

4.2.3 Definition of Equality Factor (EF)

The Equality Factor (EF) illustrates something about the quality of the pressure-distribution. The more equal the pressure-distribution is, the better. An indication of how pressure-distribution is achieved can be acquired using a cross-section of different test positions.
In order to establish the level of equality, five positions were defined in a cross-section of the test buttocks: A (near to top of thigh); B (the floating cell between top of thigh and tuberosity); C (rear of tuberosity); D (the middle of the tuberosity); and E (the front of the tuberosity).
These positions are illustrated in figure 4-7. The distance between these positions vary. The intervals between A and B, B and C, and D and E are equidistant at 50 mm. The distance between C and D and D and E is 25 mm. To give the pressure differences the same 'dimension', they have been calculated using just one distance, i.e. 25 mm. Afterall, the same pressure

differences across a greater distance will have a much less detrimental effect as the same pressure difference over a short distance.
Hobson (1992) defines the pressure gradient (or 'peak pressure gradient') as the pressure difference per mm in Hg/mm.

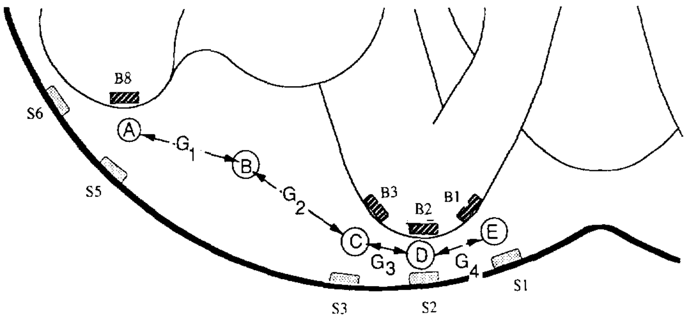


Figure 4-7 : Equality: test positions A,B,C,D and E.

The mean value of readings, taken from bone and skin sensors at the points A,C,D and E, was taken in order to determine the pressure differences:

$$P_A = \frac{B8 + S5}{2} \quad P_C = \frac{B3 + S3}{2} \quad P_D = \frac{B2 + S2}{2} \quad P_E = \frac{B1 + S1}{2}$$

The pressure at point B is gained by a process of calculation, since P_B represents the floating S7 test cell which is situated on the other side in the test buttocks.

$$P_B = \text{corrected } S7 = \frac{B8 + B2}{B9 + B4} \times S7$$

This formula is based on the assumption that the relationship between the pressures in the thigh sensors B8 and B9, the floating sensor S7 and the central tuberosity sensors B2 and B4 are the same on the left and right-hand sides.
The following four pressure differences were calculated:

The differences in pressure can be mathematically converted to factors

$$D1 = \frac{| P_B - P_A |}{2}$$

$$D2 = \frac{| P_B - P_C |}{2}$$

$$D3 = | P_C - P_D |$$

$$D4 = | P_D - P_E |$$

situated between 0.4 and 1.0. It was decided to use this scale because the average of the pressure differences across the test positions in this way will provide an EF index somewhere between 0.70 and 0.90. An EF outside this range would have a greater effect on the end result than has been presented in section 4.2.2.

In designating the size of the equality factor to an established pressure difference, it should be based on the negative effect which this pressure difference has on the internal load and on the influence which this factor has within the formula in relation to the uprating/downrating of the PD. Data using this approach is as yet not available in any literature on the subject. The eventual relationship developed was arrived at by carrying out calculations on many different arithmetic models. The results of these were tested against the starting point in order to arrive at a EF of 0.7 and 0.9 in the survey. This would limit the influence on the end result to within 13% on either side, and to the results for cushions which are known to have good pressure-distribution characteristics.

For this reason the conversion of pressure differences on the 0.4 - 1.0 scale is not linear, so as to afford greater discrimination for pressure differences which are small.
The four different equality factors were calculated using the following formulas:

$$E1 = 1 - \frac{D1}{f(D1)}$$

$$E2 = 1 - \frac{D2}{f(D2)}$$

In which:

$$E3 = 1 - \frac{D3}{f(D3)}$$

$$E4 = 1 - \frac{D4}{f(D4)}$$

$$f(D) = 2 \times \left[\frac{D}{20}\right]^2 + 2 \times \left[\frac{D}{20}\right] + 140$$

This relationship between pressure difference and equality factor is illustrated graphically in the figure 4-8.

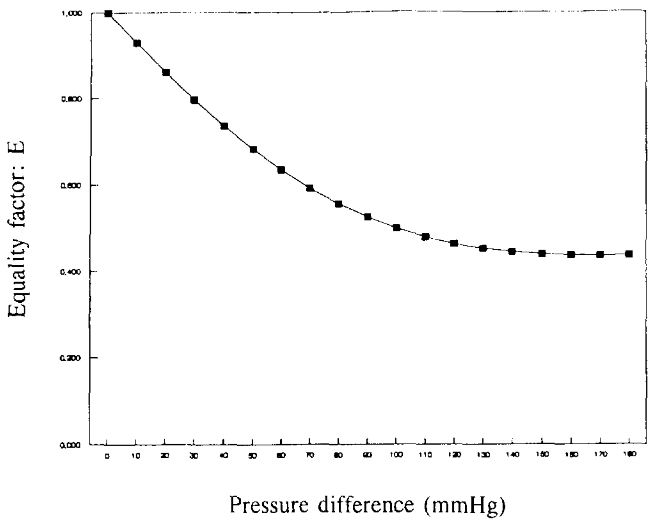


Figure 4-8 : The relationship adopted between pressure difference in mmHg on defined positions at a distance of 25 mm from each other and the equality factor E.

A difference of 30 mmHg produces an E factor of 0.797, a difference of 60 mmHg, 0.634. A difference of 60 mmHg in internal pressure on two positions at a distance of 25 mm from each other is considered to be high in this case.

Since the mean value of E1 in the cushion survey (n=87) is almost 1:

$$\bar{E}1 = 0{,}967 \qquad SD = 0{,}029$$

it was decided to calculate the equality Factor EF as an average of E2, E3 and E4. This results in the EF having a greater discriminating power on the eventual outcome. The EF is now:

$$EF = \frac{(E2 + E3 + E4)}{3}$$

Table 4-8 presents a list of overall values of the different equality factors which were generated by the survey, including tests carried out on experimental cushions.
These results are compared with the results taken from the reference Demo F 100 mm DRAKA 9019 foam cushion on a flat board.

	minimum	maximum	mean	SD	Demo F
E1	0.858	0.999	0.967	0.029	0.976
E2	0.527	0.936	0.786	0.075	0.840
E3	0.461	0.996	0.732	0.141	0.696
E4	0.436	0.922	0.587	0.113	0.602
EF	0.515	0.892	0.702	0.094	0.713

Table 4-8 : Upper and lower recorded values for equality in relation to the results taken from Demo cushion F (n = 87).

It appears from the figures above that factors E2, E3 and E4 can have both low and high values. The values for each of the separate factors lie between the adopted limits of 0.4 to 0.9. The EF in the survey however was between 0.515 and 0.892 with a mean value of 0.702. The influence of EF on the end result is on the lower end of the scale and therefore greater than formulated in the original hypothesis. As there is a relatively high correlation between the level of PD and the level of EF (0.912), the result was found to be acceptable. The relationship between PD and EF is revealed in scatter diagram form in figure 4-9.

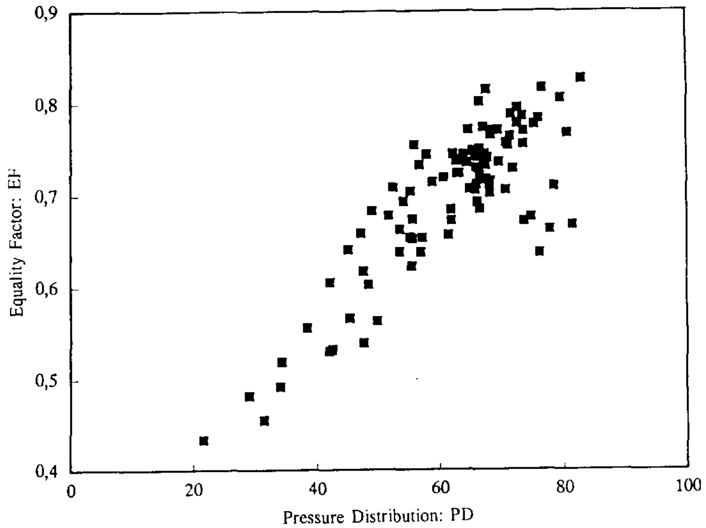


Figure 4-9 : Scatter diagram showing the relationship between the Pressure-distribution: PD and the equality factor: EF (n = 87 , r = 0.912).

Cushions, evidently, have a great influence on pressure differences, arising as a result of load, and in turn on the quality of the pressure-distribution.
In this way the EF does in fact function as the quality factor for pressure-distribution, as indeed it should. Whether or not the premises in this respect are fully correct, will be revealed on the basis of investigations on tissue into the effect of pressure differences and/or on the basis of practical evaluation. Since EF remains a 'new quantity', PDQ results will together with the separate results for PD and EF act as indices for the cushion concerned.

4.2.4 Reproducibility of pressure-distribution quality

Section 4.1.5. lists the results of 46 readings on separate test sensors over a period of 10 months on the so-called pre-cushion: the 100 mm DRAKA 9018 foam cushion on a flat board without a cover.
Table 4-9 lists the mean results of the PDQ calculation, the PD and the EF together with the standard deviation (SD) on the basis of these tests.

PDQ_{mean}	= 59.9	SD	= 2.0
PD_{mean}	= 67.9	SD	= 2.1
EF_{mean}	= 0.71	SD	= 0.01
n	= 46		

Table 4-9 : Mean results taken on pre-load cushion: '100 mm Draka 9018 foam on flat board without cover' over a 10 month period (n = 46)

As was done in section 4.1.5, results taken over a period of 3 to 4 months were also calculated. These are shown in table 4-10.

3 months	1st period	SD	2nd period	SD	3rd period	SD
PDQ_{mean}	61.4	1.20	60.8	1.30	57.7	1.10
PD_{mean}	69.1	1.10	68.9	1.90	65.7	1.10
EF_{mean}	0.71	0.01	0.71	0.01	0.70	0.01
n =	12		19		15	

Table 4-10 : Mean results taken on pre-load cushion: 100 mm DRAKA 9018 foam per period of 3 months.

The conclusion can be made that there is a marked deterioration of 3.7 points in respect of the pressure-distribution quality (PDQ). The primary cause of this is the deterioration in the pressure-distribution (PD).
Over the whole period a result of PDQ = 60 is achieved with an SD of 2. The mean SD per period of three months is 1.2. This result, despite the effect of the ageing process experienced on the part of the pre-load cushion, enables us to qualify both the test buttocks and the processing methodology of the test results as being sufficiently reliable.

4.3 Analysis of test results for the experiments

In order to gain some understanding of the effects of the test methods and the processing of results for each separate sensor in the indices defined (PDQ, PD and EF) as well as each separate factor, E1, E2, E3 and E4, this section will present and analyze the results of the experiments as detailed in chapter 3. It will deal with the influence of the thickness of the foam and the effects of the support structure and the cover on the pressure-distribution.
The results are listed in table 4-11.

cushion		PDQ	PD	EF	E1	E2	E3	E4	max. pressure mmHg
DRAKA 9018 foam on flat board without cover									
thickness:	60 mm	34	51.8	0.531	0.943	0.705	0.450	0.437	319
	80 mm	49	62.9	0.622	0.946	0.782	0.577	0.506	216
	100 mm **)	64	70.3	0.723	0.954	0.832	0.734	0.604	161
	120 mm:	75	75.2	0.796	0.963	0.876	0.838	0.675	126
DRAKA 9018 foam on 'trampoline' thickness 80 mm									
without cover		78	76.6	0.815	0.954	0.851	0.954	0.641	117
+ thin stretch		78	75.9	0.817	0.968	0.840	0.961	0.650	117
+ woollen woven fabric		71	74.1	0.769	0.966	0.814	0.919	0.575	135
+ thick stretch		69	74.0	0.747	0.970	0.883	0.754	0.604	141
+ vinyl		67	73.5	0.731	0.967	0.858	0.766	0.569	152
+ hydrolon		66	72.8	0.726	0.961	0.792	0.858	0.529	146
+ woven cover plus coating		61	70.8	0.690	0.973	0.803	0.769	0.497	163
test buttocks in own mould		69	73.5	0.755	0.941	0.899	0.662	0.709	153

*) DRAKA 9018: density 35 kg/m^3; hardness 110 N

**) reference cushion

Table 4-11 : The results of the experiments.

In chapter 3 the 'maximum pressure under the tuberosities' of the experiments was used to analyze the pressure-distribution performance of foam cushions. The influence of the cover was also discussed in these results as well as the test buttocks' own pressure-distribution capacity. It was shown that a cushion performs well when it is capable of conforming to the shape of the buttocks with the smallest possible reaction forces. In such a situation the buttocks will show a minimum of deformation, thereby optimising the pressure-distribution capacity of the buttocks themselves.

Having processed the test results, the following conclusions can be made:
The reduction in maximum pressure from 319 mmHg to 126 mmHg with an increase in thickness can be transposed into a pressure-distribution quality (PDQ) of 34 to 75.
All the factors which go towards producing a good pressure-distribution quality

- pressure-distribution (PD), the equality factors E1, E2, E3 and E4 - increase with an increase in foam thickness. The figures show a constantly rising tendency.
It is interesting to analyze the effect of the trampoline as a support structure on the pressure-distribution for 80 mm foam.
Pressure-distribution (PD) increases compared to the flat board as a support structure from 62.9 to 76.6, an increase of 22%. The EF on the other hand increase by 31% from 0.622 to 0.815. The E3 and E4 factors show a substantial increase. This means that the pressure differences are reduced in situ, thus signalling an increase in the quality of pressure-distribution. The PD in the PDQ value is uprated from 76.6 to 78 on account of the EF rising above 0.800. In relation to the 80 mm on a flat board the PDQ result increases by 59% from 49 to 78.

The influence of the cover on the pressure-distribution manifested itself in a reduction of EF and to a lesser extent in PD. The so-called 'hammock effect' appeared to lead to extremely *localised* pressure increases, resulting in turn in a reduction in EF. The increase in maximum pressure on the central tuberosity cell does not rise in the same proportion as the rise in pressure for the adjacent cells. By using an imitation leather cover, the PD was reduced only marginally from 76.6% to 73.5%. In particular the E3 factor - between the middle and rearmost tuberosity sensor - and the E4 factor - between the middle and the frontmost tuberosity sensor - showed considerable reductions from 0.954 to 0.766 and from 0.641 to 0.569 respectively, thus reducing the EF noticeably. The hammock effect resulting from the use of an imitation leather cover is converted into an PDQ reduction of 11 points.

The use of the test buttocks as a means of measuring pressure-distribution appeared to show a great degree of sensitivity. The processing methodology also proved to be extremely effective, not only in analyzing the actual effects on the cushion, but also in the numerical transformation of the test results. Indeed this was the original intention.

Table 4-9 lists the results of the pressure readings for the test buttocks when using their own inverse shape as a support structure, that is, the mould. This formed a sort of custom-contoured seat, even though it was high-sided and made from rigid material. The outcome is a PDQ of 69. Even more interesting, however, is the way in which this figure was arrived at.
The pressure-distribution (PD) appears to be quite considerable (73.5) and similar to the PD of foam with a thickness of 120 mm. The EF however is lower, in particular on account of E3 being low (0.665). This is the difference in pressure between the middle tuberosity cell and the rearmost one. This might be explained by the fact that the tests buttocks evidently undergo some deformation, however slight, before the mould, in its entirety, starts to have an

effect on the pressure-distribution. The mould as such is non-deformable and has no further 'active' part to play in the pressure-distribution, the reaction forces being dependent on the way in which the buttocks via the pelvis, tissue and skin transmit the forces to the support unit. If E3 has a value of e.g. 0.80 then the PDQ is increased to 76.

From the results taken from the test buttocks in their own mould it can be concluded that the buttocks' own pressure-distribution capacity can be optimised when their form is modified as little as possible. Each pair of buttocks will have their own specific pressure-distribution capacity, which is contingent on the amount of soft tissue.
Section 5.2 discusses the results taken from a number of readings for a 'special contoured seat' which, with the aid of a commercially available system, was manufactured specifically for the test buttocks.

4.4 Comparison of Test buttocks and OPM results

In order to enable a comparison of the pressure data on the test buttocks with the interface pressure, as can be achieved using the Oxford Pressure Monitor and other similar equipment, an extra test was carried out on each cushion within the framework of the survey. This was done in order to determine the interface pressure between the test buttocks and the cushion. Three rounded OPM cells with a diameter of roughly 15 mm each were placed on the positions, marked under the S1, S2 and S3 sensors on the test buttocks. The OPM values as well as the test buttocks' values were recorded for comparison. The data on the test buttocks could also be compared with values from a previous experiment without use of the OPM so that an impression could be had of the effects of the test sensors on the amount of internal pressure.
Figure 4-10 presents a scatter diagram of the relationship between the OPM interface under S2 and the corresponding value recorded by the S2 sensor on the test buttocks. The correlation coefficient between these parameters is 0.85. The comparison of the regression curve of both sets of test readings results in a factor of 1.45 and a constant of 0.0. This means that the S2 test buttock = $1.45 * OPM_{under\ S2}$

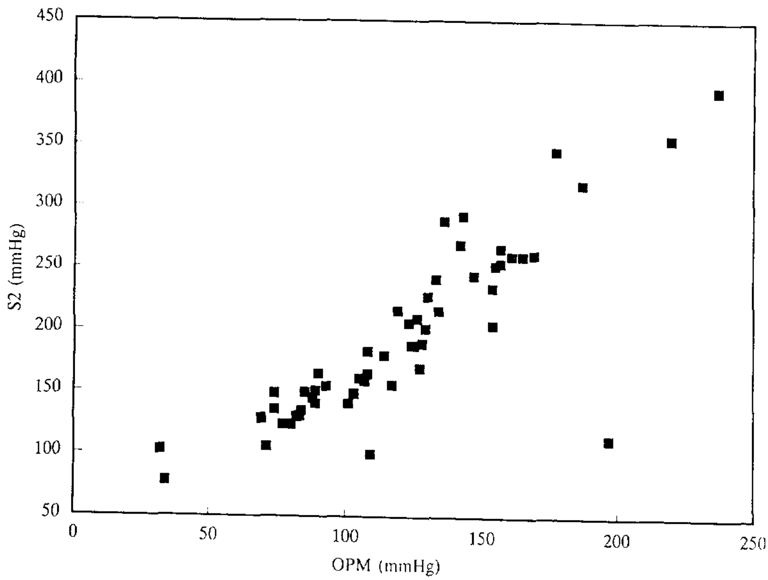


Figure 4-10 : The relationship between the interface pressure $OPM_{under\ S2}$ and the internal pressure behind the skin in the S2 sensor.

Figure 4-11 shows the relationship between the interface pressure ($OPM_{under\ S2}$) and the value registered by the B2 sensor. The regression comparison of these two variables is:

$B2_{test\ buttocks}$ = 1.71 * OPM value

for a correlation of 0.847 between both factors.

These results are in general similar to those found in Le's study (1984) mentioned previously. These showed that the pressure on the side facing the bone is higher than that registered on the side facing the skin.

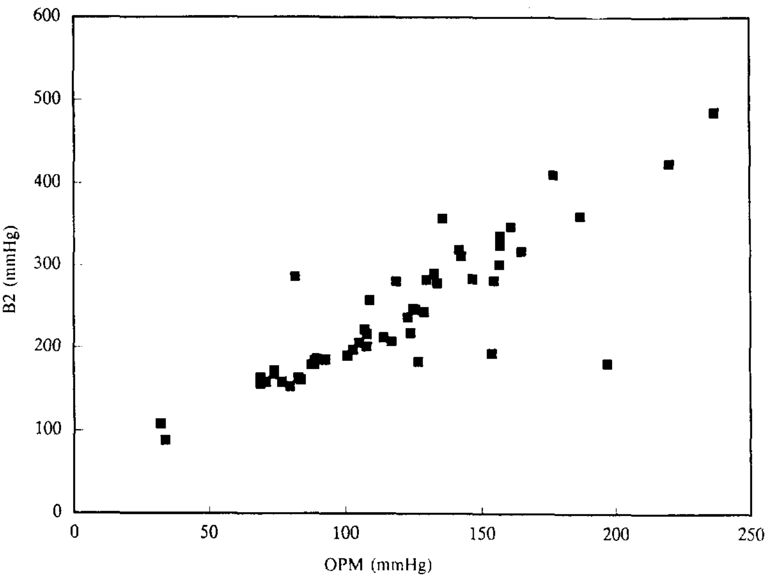


Figure 4-11 : The relationship between the interface pressure OPMunderS2 and the internal pressure on the tuberosity in the B2 sensor.

Figure 4-12 demonstrates the effects of the OPM test cell with a 15 mm diameter, however slight, on the way in which the internal pressure is produced, by comparing it to the result of the S2 sensor without the OPM test cell. The OPM cell seems to raise the internal pressure on average by 12.04 mmHg. The 95% confidence interval is located between 16.3 and 7.8 mmHg. The difference with and without the use of the OPM test cell appears to be significant.

The reproducibility of tests on the test buttocks should indeed take into consideration the significance of the difference. Over 46 readings taken from the pre-load cushion (100 mm DRAKA 9018 foam) gave an S2 sensor value of 146.3 mmHg with an SD of 4.5 mmHg. Expressed in percentage terms this represents an SD of 3.0 %. The B2 has an average value of 173.5 mmHg with an SD of 6.5 mmHg (or 3.7%). The influence of the OPM test sensor on the test results was found to have a mean value of 6.2 %. This explains the significance found.

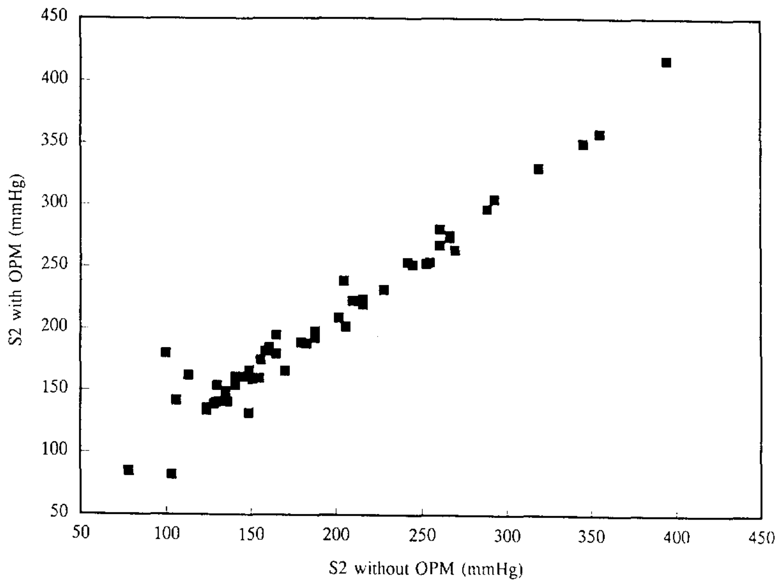


Figure 4-12 : The influence of the OPM test cell on the internal pressure: S2with OPM in relation to the S2without OPM.

In order to find out what kind of effect the *type* of cushion has on the results, table 4-12 compares the results for a number of different cushions. The differences between the test buttocks' value with and without the use of the OPM are listed under the heading S2opm-S2 and B2opm-B2 respectively. Conspicuous is that the difference appears to strongly depend on the type of pressure-distribution medium. For most cushions the effect produced is that the S2 value is higher as a result of using the OPM. Air-filled cushions, where the load is spread across a number of different sections, show an anomalous picture. For these cushions the OPM sensor seems to spread the reaction forces more evenly across the skin, due to the favourable mechanical effects of the sensor on the internal pressure.
The average relationship between the B2 value and the OPM value for air-filled cushions was 2.57, whilst the average for all cushions was 2.0 with an SD of 0.39. The factor in the regression comparison of these variables was 1.71, as has already been established. In relation to other types of cushions, air-filled cushions - where the load is spread across a number of different surfaces - produce relatively favourable results when using the OPM.
Due to other priorities this material was not analyzed further. Nevertheless the conclusion can be drawn that these results justify the manufacture of the test buttocks and that the test instrument does indeed affect the results in the case of the OPM.

number	pressure-distribution medium		S2	B2	OPM	S2opm - S2	B2opm - B2	B2/OPM
15	foam	mean	185.3	214.5	114.4	8.8	14.0	1.87
		sd.	43.7	51.0	25.2	5.7	6.7	
3	air,		103.3	115.7	45.0	-1.0	-0.3	2.57
	split surface		25.5	24.0	20.8	17.7	10.3	
4	air, non-split surface		129.7	149.2	78.8	19.0	20.5	1.89
	air/foam, idem ditto		20.0	18.9	11.1	13.8	10.0	
5	liquid gel		168.0	195.6	94.4	3.6	7.6	2.07
			58.7	72.7	29.6	15.9	17.8	
4	non-liquid gel		305.7	395.5	173.3	11.5	9.5	2.28
			63.5	53.7	46.1	7.7	10.9	
2	fibres		231.5	259.0	140.5	16.5	4.5	1.84
			30.4	33.9	20.5	9.2	9.2	
5	gel on foam		230.8	264.4	137.6	7.0	5.4	1.92
			100.0	117.0	61.9	3.6	3.2	
4	visco-elast.foam + foam		221.7	264.5	136.8	12.8	12.5	1.93
			53.1	65.3	24.4	3.8	4.1	
1	'filled' hammock		242	273	133	12	17	2.05
43			mean:			9.30	10.95	2.00
			SD:					0.39

Table 4-12 : The relationship between the OPM test values and the internal pressure in the S2 and the B2 pressure sensors and the influence of the OPM-pressure test cell on the internal pressure in relation to the pressure-distribution medium. (mmHg)

4.5 Assessment of the pressure-distribution quality: PDQ in relation to user groups

In order to establish assessment criteria in respect of pressure-distribution quality (PDQ) in relation to the pre-defined groups of wheelchair-users, a panel of user-experts was asked to assist. The panel comprised persons from different disciplines, all of whom had experience with regard to assessment and prescription of wheelchair-cushions.
During a specially organised 'panel-discussion day' a large number of choices were made, using existing cushions, which were then converted into assessment criteria on a more or less systematic basis.
This section will explain the way in which the wheelchair-cushion panel went about their work and the results presented.

The wheelchair-cushion panel of 9 persons contained representatives from the following disciplines: occupational therapy, physiotherapists, one rehabilitation consultant and a medical insurance technician. The size of the group was kept to a minimum, in order to produce a workable outcome.

The wheelchair-cushion user groups, categorised in section 2.1.1, provided the basis for the formulation of assessment criteria. 5 different types of cushions were identified by these groups:
- a low-risk user cushion
- a medium-risk user cushion; normal
- a medium-risk user cushion; transpiration
- a high-risk user cushion; transpiration
- a high-risk user cushion; incontinence.

In order to define assessment criteria in respect of pressure-distribution quality, the following plan of action was adopted:

A so-called 'panel discussion day' was organised to which panel members were invited. For the purposes of the exercise 17 different cushions were selected which included well-known cushions, already on the market as well as experimental cushions. The test results for these cushions were known only to the researchers and not to the panel members.

The following types of cushions were selected:

1.	air/foam cushion on hammock	
2.	foam + gel on flat board	
3.	siliconized fibre on hammock	
4.	latex foam on webbing	
5.	foam on hammock	
6.	liquid gel on pre-formed shell	
7.	gel on foam on flat board	
8.	air in foam on flat board	
9.	foam + T-foam on flat board	
10.	liquid gel on foam on flat board	
11.	air cushion with large number of cells on flat board	
12.	demo A:	vinyl, horsehair on trampoline
13.	demo B:	stretch, composite foam on trampoline
14.	demo C:	stretch, disposable incontinence material, hydrolon, horsehair on flexible frame
15.	demo D:	fabric, horsehair on trampoline
16.	demo E:	stretch, composite foam on flexible frame
17.	demo F:	stretch, 9018 foam on flat board.

These cushions were placed on chairs with an active sitting posture, specially-designed for the occasion. The cushions were positioned in the chairs in such a way that a comparable functional sitting height could be attained. Each

participant was given his or her own footrest which was adjusted to the length of the lower leg. In this fashion all members of the panel could feel the cushions in the same way and therefore achieve an expert verdict.
The general formulation of the question was:

Is a cushion, exclusively in relation to one specific attribute, suitable for a particular user group?

Answers were divide into *yes; no; and 'maybe'*.

All seventeen cushions were given scores by the 9 panel members.

Then the chairs with the cushions were put in order according to the measured pressure-distribution quality (PDQ).
Panel members were then asked to indicate which cushions were suitable for which user groups.

In a plenary session both results were discussed and together a number of conclusions were made. In this way the 'state-of-the-art' status of cushions currently available were also taken into account.
For each type of cushion a 'target' level, an 'acceptable' level and an 'unacceptable' level were established.

This resulted in the following:

	target level	acceptable level	unacceptable level
low-risk user cushion	≥ 60	45 - 65	< 45
medium-risk user cushion	≥ 65	55 - 65	< 55
high-risk user cushion	≥ 75	65 - 75	< 65

Table 4-13 : Assessment criteria for pressure-distribution quality: PDQ. (PDQ).

The unacceptable level was used as a 'threshold' level. Cushions not attaining this level were not classified under this particular type. In this cushion survey - the first using a continuous series - two exceptions were made. The threshold value for the low-risk user cushion was set at PDQ $\geq$ 30 and for the high-risk user cushion, incontinence at PDQ $\geq$ 55. In section 6.5 (Analysis of combinations of attributes) these are discussed in more detail.
The pressure-distribution results of all cushions in the survey were discussed retrospectively with the panel in relation to the assessment criteria which had been developed. This did not result in any discrepancies with quality tested empirically. By using the methods which were developed for the assessment criteria this came as no surprise.

In order to attain a more objective idea of the size and weighting of these assessment criteria, relevant literature was consulted to provide comparative material. The survey which came the closest was that carried out by Bar, mentioned previously. The following section will compare his results and criteria against the results of this survey.

4.5.1 Comparison of the selected assessment criteria and Bar's criteria

A short summary was given in section 2.4 of the aims and results of Bar's study (1988). Bar drew a link between the mean dynamic interface pressure, measured over a period of 2 hours, and the temperature reaction of the skin in relation to erythema. On the basis of the so-called pO2 cut-off pressure, which was validated for healthy test subjects, the pressure histograms were translated into areas where oxygen debt (D) is dominant and areas where oxygen recovery (R) has taken place. Bar relates the R/D ratios, found in the study between these variables, to the tissue reactions defined and to the mean dynamic interface pressures measured.
The results of this exercise are reproduced in figure 4-13.

RESPONSES (n = 150)	**R/D Ratio** $\mu \pm s$	**μP** (mmHg)
Mild (n=102)	7.8 ±4.6	≤ 80
Moderate (n=24)	2.4 ±1.9	60 -115
Severe (n=24)	0.6 ±0.5	≥ 90

Figure 4-13 : Bar's (1988) relationship between mean interface pressure (μP), the R/D ratio and the skin reactions defined: mild, moderate and severe.

It is an interesting exercise to consider whether Bar's results can be compared retrospectively with the assessment criteria for the pressure-distribution quality (PDQ) in this survey and what the results might be of this comparison. A certain degree of correspondence between the two would after all provide a firmer footing for these criteria.

The analysis given here can only serve as a rough approach since subjective interpretations need to be made. This analysis will therefore concentrate on the initial level of comparison.

The pressure-distribution quality (PDQ) is based on the test results of a large number of test sensors situated *in* the test buttocks.
The so-called interface pressure in the survey was determined by placing an OPM between the test buttocks and the cushion. A position directly underneath the S2 sensor was selected which was similar to Bar's positioning.
Using this OPM value a link, in theory, can be made between the internal S2 pressure, the PDQ calculated and the results of Bar's analyses.
The biggest problem faced in doing this is the question of how the mean dynamic pressure readings, taken over a period of 2 hours, can be translated into the results of a static laboratory tests.
If it is assumed that the amount of pressure measured statically corresponds to the pressure which occurs *the most frequently*, then the OPM test buttocks' reading could best be compared with the '*modus*' value in Bar's histograms.
If it is assumed that the pressure measured statically corresponds most closely with the amount of *mean* dynamic pressure, then a comparison with the mean pressure (μP) would not be out of place. The 'modus' approach would seem to be the most plausible, but since Bar himself expresses the results in 'mean-pressure', it was decided in this first analysis to adopt this measurement.

The cushion survey carried out tests using the OPM readings whilst at the same time readings were taken from the test buttocks' sensors. From this data it is possible to establish a link between the OPM values measured and the associated PDQ. The influence of the OPM on the test results has therefore been ignored. The relationship established is presented in graph form in figure 4-14
The correlation between both parameters is high (0.818). The formula for the regression comparison between both parameters is:

$$\text{OPM} = 216 - 1.956 * \text{PDQ} \quad ,$$

calculated with the OPM as an independent variable,

$$\text{PDQ} = 90 - 0.340 * \text{OPM} \quad ,$$

calculated with the PDQ as an independent variable.

From both of these linear relationships a mean correlation can be established between the interface pressure, OPM, and PDQ plus and minus half the difference between the two lines.

OPM = 60 → PDQ = 75.5 ± 5.5
OPM = 80 → PDQ = 66.5 ± 3.5
OPM = 100 → PDQ = 57.5 ± 2.5
OPM = 120 → PDQ = 48.5 ± 1.5

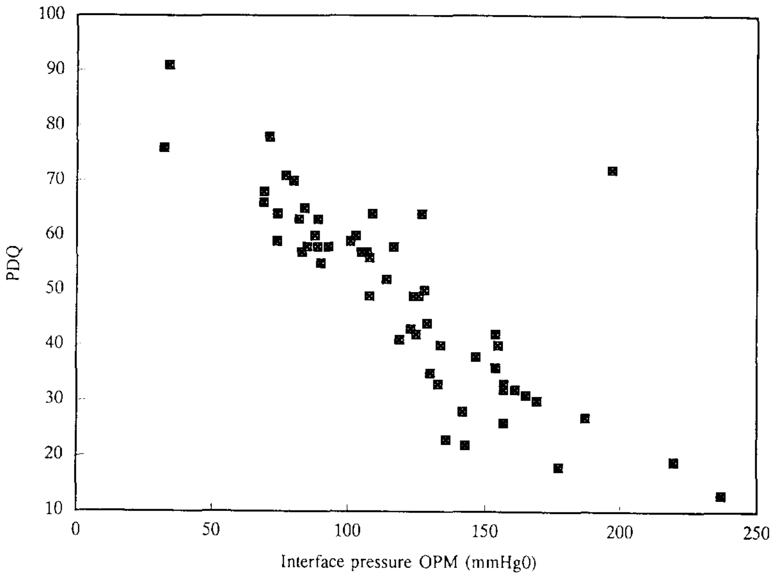
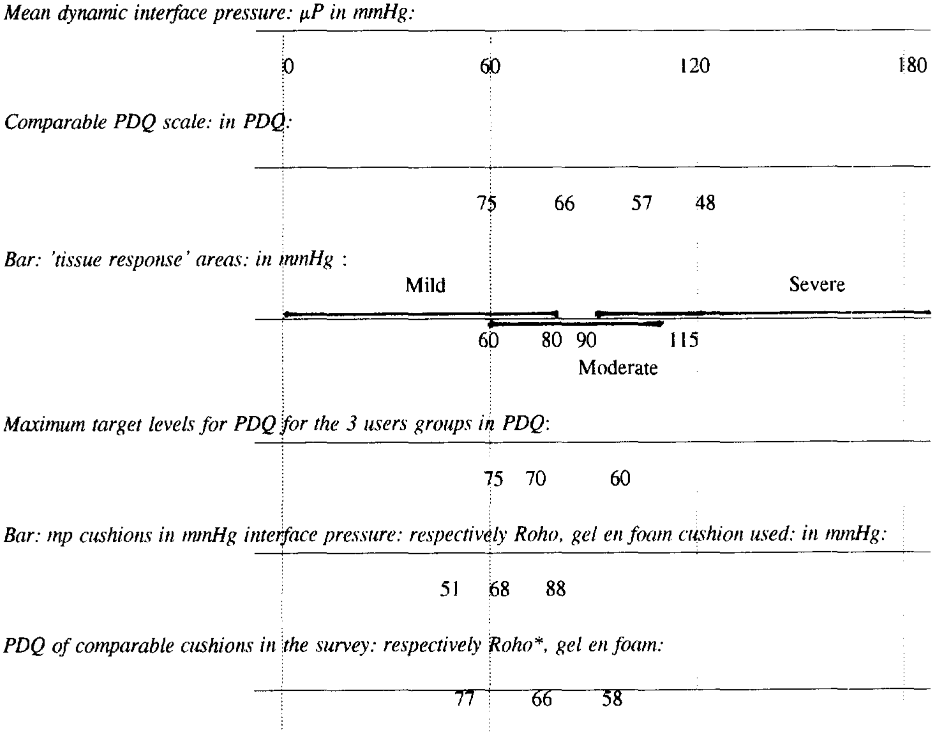


Figure 4-14 : The relationship between OPM test value under S2 and the PDQ calculated on the basis of test values without use of the OPM.

Figure 4-15 lists the different data from both of these surveys in their mutual context.



* average taken from 11 tests.

Figure 4-15 : Comparison of cushion-survey results with Bar's results (1988).

The 'moderate' area of the tissue response appears to be situated between a
PDQ of 75 $\pm$ 5 and 51 $\pm$ 2 ,
the area of 'mild response' has a
PDQ of $>$ 66 $\pm$ 3.5
and the area of 'severe response' has a
PDQ of $<$ 62 $\pm$ 3 .

For the different individual types of cushion the high-risk user cushion (HRUC), the medium-risk user cushion (MRUC) and the low-risk user cushion (LRUC), the assessment levels for the PDQ as listed in section 4.5 are placed respectively in:

the target level for:	PDQ > 75, PDQ > 65 en PDQ > 60.
the acceptable level for:	PDQ > 65, PDQ > 55 en PDQ > 45.

The target level values all lie in the area of 'moderate tissue response'. The target level for the high-risk user cushion (PDQ=75) is situated in the 'mild response' area on the overlap with the 'moderate' area. The target value for a medium-risk user cushion is situated in the 'moderate' area on the border with 'mild'.
The target value for the low-risk user cushion is situated in the 'moderate' area close to the beginning of the 'severe' area. This cushion is clearly not intended for the test subjects in Bar's study, who on the basis of their characteristics can all be categorised as belonging to those user groups for the medium-risk user cushion or the high-risk user cushion.

Figure 4-15 also lists the PDQ and the μP of cushions used in Bar's study. The values for the gel and the foam cushion are based on comparable cushions taken from this survey. These values indicate the probable size of the PDQ and must be treated with some caution. The Roho value is based on a average of 11 readings. The PDQ values used for the Roho, the gel and the foam cushions are 77, 66 and 58, situated respectively in the 'mild', 'moderate' and 'severe tissue response' areas. This corresponds to Bar's conclusions and his mean interface pressure readings for these cushions.

We can conclude from this comparative analysis of the results that there is a certain degree of agreement in the conclusions which Bar makes and the target levels of pressure-distribution quality which are used in our cushion survey. In this context it should also be taken into consideration that Bar's test subjects all had spinal cord lesions and therefore are more susceptible to decubitus. Users with a spinal cord lesion generally experience atrophy of the buttock muscles and have disturbed sensibility. They would at the least be prescribed a medium-risk user cushion. 7 of the test subjects had a cervical lesion, and as such had difficulty in modifying their position and would therefore usually be prescribed a high-risk user cushion.
The buttocks of the test subjects could therefore be considered to be 'critical to extremely critical'.
In this context two important conclusions can be drawn:
In relation to Bar's results the target levels developed should be treated, in the first instance, somewhat cautiously, but are, given the critical population which Bar uses, certainly acceptable.
In addition the conclusion can be made that, given the similarities, the test buttocks have a critical size, shape and mass, as was the original intention.

Given the fact that two completely different approaches have been taken for the

same problem area, the degree of similarity can be said to be both surprising and encouraging.
The conclusion can be made that the wheelchair-cushion panel was certainly capable of using the skin-response readings, measured by Bar per person per cushion, in an empirical fashion when determining the suitability of a cushion for a certain type of user group and in turn the level of the PDQ necessary.

4.6 Influence of load size on the pressure-distribution quality

In order to gain an impression of the effects of load size on pressure-distribution, and how this is expressed in the calculating method employed, a number of trial tests needed to be carried out using different loads, once the cushion survey was completed.

A selection was made of the different types of cushion constructions. The cushions were loaded with 500 N, 600 N and 700 N. These loads compare with the sitting loads of persons weighing 67, 75 and 93 kilos respectively with an even size, shape and mass of buttocks.

In relation to the 600 N used this means a reduction (or an increase) of the test load of 16.6 %.
In calculating PDQ the PD will be measured according to the load which is exerted. The PD indicates the percentage load taken up by the buttocks excepting the area around the tuberosities. A PD of 70%, if a reverse calculation is made, means that the area around the tuberosities absorbs loads of 150 N, 180 N and 210 N for respective loads of 500 N, 600 N and 700 N. This happens roughly at the point when the internal pressure on the middle tuberosity cell B2 is 120 mmHg, 150 mmHg and 180 mmHg respectively, according to the test results of a cushion with a PD of around 70%.

The PD and therefore the PDQ are not in this case related to the amount of maximum internal pressure observed. This might be regarded as a point of criticism when making such comparison of pressure-distribution quality at different loads.
The calculation of the eqaulity factor (EF) is not dependent on the size of the load.

The results of the PDQ which have been calculated using this method are shown in the following tables.

load:	500 N	difference	600 N	difference	700 N
type of cushion:		500-600		700-600	
Foam + fabric cover on hammock	78	11	67	-7	60
Latex foam + vinyl cover on webbing	58	3	55	-3	52
Gel in foam on hammock	69	9	60	-8	52
Liquid gel on rigid shell	67	6	61	-5	56
Foam in air on shell	70	7	63	-7	56
Air with divided surface on hammock	92	3	89	-10	79
Coconut fibre + vinyl cover on trampoline	75	3	72	-2	70
Non-homogenous foam on flexible support structure	92	3	89	-4	85
mean		5.		- 5.4	
S.D.		3.16		3.16	

Table 4-14 : The influence of the size of load on the PDQ result for different types of cushions (PDQ).

The table reveals a number of provisional trends. Firstly, the best results are found for cushions given a 500 N load, then for 600 N. The 'worst' results are found for 700 N. This is to be expected. After all, pressure is increased each time using a test dummy with the same dimensions, shape and structure. A second trend which can be detected is that, with the exception of the air-cell cushion, the improvement and deterioration in PDQ, measured in terms of the difference from 600 N, are of roughly equal size. The average in difference across all readings is 5.7 points (PDQ) with an SD of 2.85.
Cushions with a more flexible support structure are found to be below average.

In order to establish the reasons for this difference and what exactly the effect is on the maximum internal pressure in the B2 test cell, the results for maximum pressure, PD and EF have been isolated and are shown in Tables 4-15, 4-16 and 4-17

load	500 N	difference 500-600	600 N	difference 700-600	700 N
Foam + fabric cover on hammock	102	-49	151	42	193
Foam rubber + vinyl cover on webbing	164	-30	194	26	220
Gel in foam on hammock	135	-37	172	58	230
Liquid gel on hard shell	130	-27	157	33	190
Foam in air on shell	132	-33	165	47	212
Air cells on hammock	61	-39	100	41	141
Coconut fibre + vinyl cover on trampoline	121	-24	145	18	163
Non-homogenous foam on flexible support structure.	70	-13	83	24	107
mean				36.1	
S.D.		10.8		13.3	

Table 4-15 : Influence of the size of the load on de maximum internal pressure in the B2 middle tuberosity cell for different types of cushions (mmHg).

load:	500 N	difference 500-600	600 N	difference 700-600	700 N
Foam + fabric on hammock	81.6	10.7	70.9	-2.4	68.5
Foam rubber + vinyl on webbing	65.4	-0.4	65.8	-1.7	64.1
Gel in foam on hammock	75.3	10.2	65.1	-2.4	62.7
Gel on hard shell	62.9	1.9	61	-0.3	60.7
Foam in air on shell	69.6	2.0	67.6	-2.7	64.9
Air cells on hammock	76.5	-2.8	79.3	-2.5	76.8
Coconut fibre + vinyl on trampoline	75.2	-1.2	76.4	1.0	77.4
Non-homogenous foam on flexible support structure	78.6	-1.4	80	-0.1	79.9
mean difference with regard to 600 N		2.72		-1.38	
S.D.		5.04		1.40	

Table 4-16 : Influence of the size of load on the pressure-distribution PD for different types of cushions (%).

load:	500 N	difference 500-600	600 N	difference 700-600	700 N
Foam + fabric on hammock	0.768	0.007	0.761	-0.061	0.700
Foam rubber + vinyl on webbing	0.715	0.050	0.665	-0.001	0.664
Gel in foam on hammock	0.732	0.000	0.732	-0.069	0.663
Gel on hard shell	0.850	0.045	0.805	-0.062	0.743
Foam in air on shell	0.801	0.054	0.747	-0.054	0.693
Air cells on hammock	0.963	0.063	0.900	-0.081	0.819
Coconut fibre + vinyl on trampoline	0.795	0.039	0.756	-0.035	0.721
Non-homogenous foam on flexible support structure	0.933	0.044	0.889	-0.036	0.853
Mean difference with regard to 600 N		0.038		-0.050	
S.D.		0.022		0.025	

Table 4-17 : Influence of the size of load on the equality factor (EF) for different types of cushions.

From tables 4-16 and 4-17 the conclusion can be made that the influence of the EF on improvement or deterioration in the PDQ under the influence of load is greater than the influence of the PD. The mean difference in EF of 0.50 with an SD of 0.025 can be translated into a mean difference of 4.4 PDQ points with an SD of 2.2. The mean difference in PDQ was 5.7 PDQ points with an SD of 2.85, so that the influence of the EF on this can be deemed significant.

These experiments using different loads and the influence of these in establishing the pressure-distribution quality of a cushion allows us to draw a number of discreet conclusions.
The level to which the selected cushions/cushion systems are representative for the assessment of the test method, in ascertaining the pressure-distribution quality of a cushion, and the influence of load on it cannot accurately be assessed.
Nevertheless the conclusion seems to be justified that testing of the pressure-distribution at 600 N for therapists by comparison provides a good indication of the pressure-distribution qualities of a cushion, as long as the dimensions, shape and mass of the test buttocks are considered in relation to the corresponding characteristics of the user. The influence of weight is more or less predictable, at least for buttocks with a constant size, shape and mass. The influence of the buttocks' 'size' is by comparison predictable, if the theory formulated is applied as long as the size and construction of the cushion is matched to the dimensions of the buttocks.

4.7 Summary and conclusions

In order to be able to test the pressure-distribution performance of a sitting support under laboratory conditions, an artificial set of buttocks was designed, the shape, size and structure of which are comparable to those of a human. Within this testing instrument, called the 'test buttocks', 19 pressure sensors were fixed at strategic locations on the 'pelvis' and behind the 'skin'. Shape, size and load of the test buttocks are critical, which means that there is a relatively small amount of soft mass for the preferred load of 600 N, that is, the sitting weight of a person of 75 kilos.
The test buttocks appear to be a very sensitive test instrument. Slight changes in the surface of a cushion under load, such as with a small and thin OPM test sensor, are observed as a significant increase in internal pressure.
The test results of the test cells in relation to each other generally correspond to those which might be expected if we take existing literature as a basis. The highest pressures are recorded internally in the region of bone protuberances, decreasing outwards. The more soft tissue between bone and skin, the greater the difference in pressure and the smaller the absolute value. Soft tissue serves as an internal pressure-distribution medium.
The accuracy of testing individual test cells was analyzed on the basis 46 tests taking place over a period of 10 months using the so-called pre-load cushion. Together, all test cells had, over a period of 3 and 4 months, a mean Standard Deviation of 3.51 mmHg. This result can be considered to be reliable.

The test data was processed using a method based on the principle of the amount of pressure-distribution and the principle of quality of pressure-distribution: the equality of pressure-distribution. The pressure-distribution (PD) is defined as being the percentage of the load which is absorbed by the buttocks excluding the two areas in the vicinity of the tuberosities. The equality of pressure-distribution is based on the pressure differences between 4 pre-defined places in a cross-section of the buttocks and is expressed in a factor between 0.4 and 0.9. The average of three of these factors is used as basis for the equality factor. Both these indices have been combined to form one single index which indicates the pressure-distribution quality (PDQ) on a scale of 0 to 100. This index and in particular the PD and EF indices which go towards defining the PDQ, appear to provide a valuable insight into the way in which the pressure-distribution in a cushion is realised. The detrimental hammock effect could be very clearly shown as a result of a reduction in the EF or an increase in pressure differences.
The pressure-distribution quality (PDQ) had a mean standard deviation of 1.2 when measured for the 46 tests on the pre-load cushion in the 3 to 4 monthly periods.

Using a panel of experts a set of assessment criteria was systematically developed. Panel members were asked to give their verdict on the suitability or not of certain attributes of a number of selected cushions in relation to five pre-defined user groups.These results were systematically processed into assessment criteria and then returned to the panel for further observations.The assessment criteria for the pressure-distribution quality were then compared with interface results which Bar recorded in his research work. This was made possible by the fact that the test buttocks were also tested for interface pressure. In a separate test an OPM cell was applied directly under the internal central tuberosity cell S2, from which the interface pressure was ascertained. The similarity between Bar's results and the assessment criteria was surprisingly good, certainly when we consider the two completely different approaches which were made. The assessment criteria used appear to correspond more or less with the critical limits which Bar determined. Furthermore, on the basis of characteristics of the disabled test subjects, the conclusion can be made from these results that the test buttocks have a critical shape, size and mass and can be loaded in a 'critical' fashion. This was what the survey had in mind in the first place.

The influence of the amount of load on the pressure-distribution results and the data-processing methods were investigated by loading a selected range of cushions with 500 N, 600 N and 700 N. This can be compared to the total weights of persons weighing 67 kilos, 75 kilos and 95 kilos, with buttocks consistent with the shape, size and mass of the test buttocks.
In relation to the 600 N load most cushions appeared to show improvements or deterioration in terms of results which gave a more or less symmetrical picture, corresponding to the effects which one might expect in practice; i.e. a smaller load provides a better pressure-distribution than a greater one; flexible support structures react better to changes in load than rigid constructions.
This observation enables us to conclude that the test method used for loads of 600 N provides for therapists by comparison a good indication of the pressure-distribution qualities of a cushion, as long as the dimensions, shape and mass of the test buttocks are considered in relation to the corresponding characteristics of the user.

5.0 Pressure-distribution quality of cushion systems

In theory the pressure-distribution of any cushion can be analyzed, predicted and understood on the basis of the four suppositions given in the summary and conclusions of chapter 3.0:

- To what extent does the support structure contribute to the conformity with the shape of the buttocks? In other words, to what extent will the pressure-distributing medium be indented, or - in the case of foam - what level of relative indentation will be produced?
- What is the link between the indentation and reaction force of the pressure-distributing medium being used?
- To what extent does an (undesirable) tensile stress develop in the surface under load in its entirety and what is the influence of the cover on this phenomenon?
- Is the pressure-distribution medium capable of reducing localised reaction forces under the ischial tuberosities?

These questions evolved in the course of the survey after analysing the cushion data obtained. The experience gained in the design of cushions according to certain principles and expectations has also helped in developing this theory. By using specially designed cushions it was possible to put these principles to the test.

Reference to these questions was indeed made during the survey, in order to estimate the pressure-distribution quality of a cushion and to then measure this up against the recorded PDQ result, for example, in order to subsequently establish by analysis whether or not the hammock effect is greater than was estimated beforehand.

As well as providing a basis for subjective assessment of pressure-distribution, these premises can also be applied to clinical situations where the pressure-distribution capacity of a particular cushion is tested and assessed for a particular user.

This chapter presents the results of the pressure-distribution quality (PDQ) of cushions subjected to testing in this survey. These results are analyzed and where necessary commented on. The cushions are grouped according to their pressure-distributing medium and pressure distributing principle which they employ. The summary and conclusions section to this chapter will list the top

12 results and draw general conclusions.

Before moving on, it should be reiterated that PDQ target levels have been established for three specific user groups, that is, the low-risk user cushion (PDQ $\geq$60), the medium-risk user cushion (PDQ$\geq$65) and the high-risk user cushion (PDQ$\geq$75).

5.1 The pressure-distribution quality of foam cushions

The way in which pressure-distribution in a cushion is realised has been developed partly due to experiments with foam. The effects of its thickness, its relative indentation and the effects of the support structure on the pressure-distribution quality of foam cushions have all been examined. Chapter 3 outlined this in detail. The same four questions listed at the beginning of this chapter formed one of the main conclusions of chapter 3.0.

This section presents the results recorded for foam cushions. These will be discussed using a number of parameters: the type of support structure used, the thickness of the foam, the way in which it is employed (homogeneous or not-homogeneous, cut-out or non cut-out) and the type of cover (fabric, vinyl or stretch cover). Unfortunately, most product information does not include any information on the quality of foam.

Table 5-1 summarises the effects of the support structure on the pressure-distribution results. In addition to the mean and standard deviation values, maximum readings are included in the table, in order to indicate the strength of the various systems.

The influence of the support structure can be quite clearly identified from the results in the table. The webbed structure would seem to have a greater strength than the table would suggest. However, if the webbing is so taut that it does not sag when subjected to a load, the desired effect is not achieved. In this case the webbing can be compared to a flat board. In general the cushion results can be called 'poor' when compared to the results of experiments discussed in sections 3.2 and 4.3, in which the thickness of the foam and the influence of the trampoline as support structure were examined. For these latter experiments a 100 mm DRAKA foam 9018 on a flat board had a PDQ score of 64, whilst 80 mm DRAKA foam 9018 scored 78 when subjected to a load on the 'trampoline'.

number of cushions	support structure	PDQ mean	SD	max. PDQ
3	flat board	36	4.0	40
13	hammock	60	10.0	77
2	contoured shell	62	2.0	63
6	webbing	50	7.5	59
24 total		55	11.7	77

Table 5-1 : The influence of the support structure on pressure-distribution results (PDQ) of foam cushions.

Table 5-2 lists the results per support structure as well as foam thickness and type and the cover used. The pressure-distribution results (PDQ) are complemented by the PD and EF indices plus the maximum recorded value of pressure in the B2 sensor.

Taking these and previous results into account, the general conclusion can be made that, given foam's potential, most cushions have obviously not been designed according to the developed guidelines. Since cushion 1 (70 mm polyether foam with fabric cover on hammock) and cushion 90 (100 mm incised polyether foam with fabric cover on hammock) attained reasonable scores (PDQs of 70 and 77 respectively), the suggestion is that, for a number of cushions on a hammock structure, the foam thickness is minimal and/or the quality of the foam is too hard.

cushion no.	support structure	foam used	foam thickness mm	cover	PDQ	PD	EF	max. pressure mmHg
9	flat board	latex	60	fabric + coating	32	48.3	0.533	334
10	"	latex	60	vinyl	40	55.4	0.580	270
54	"	polyether	40	vinyl	35	49.8	0.570	312
1	hammock	polyether	70	fabric	70	72.5	0.767	143
2	"	polyether	70	fabric	65	71.0	0.728	157
30	"	polyether	70	nylon	38	52.5	0.574	278
31	"	p.u.	60	nylon	44	56.7	0.617	244
60	"	polyester down	85	gore-tex	31	45.0	0.546	327
63		latex	105	gore-tex	60	67.0	0.713	175
68	"	p.u.	55	fabric	59	67.6	0.698	182
69	"	silicone	80	fabric	58	65.7	0.711	181
87	"	latex	100	fabric	59	64.5	0.728	195
90	"	polyether incised	100	fabric	77	70.2	0.874	138
91	"	idem	85	fabric	64	66.3	0.772	183
92	"	idem	60	fabric	66	67.0	0.782	168
93	"	silicone	60	fabric	59	63.4	0.747	196
26	shell	latex	120	vinyl	60	65.8	0.728	183
32	"	p.u.	60	fabric + coating	63	68.5	0.731	166
7	webs	latex	95	vinyl	59	63.1	0.746	199
12	"	latex	60	fabric + coating	49	62.8	0.626	219
14	"	latex	60	vinyl	58	67.1	0.692	187
27	"	latex	60	fabric	52	61.9	0.672	199
28	"	latex	60	vinyl	41	55.5	0.588	269
56	"	polyether	55	vinyl	43	57.2	0.599	255

Table 5-2 : Composition and results for foam cushions.

5.2 The pressure-distribution quality of 'custom contoured seats'

The idea behind so-called custom contoured seats is that the more they resemble the individual shape of the buttocks, the better the pressure-distribution that will be achieved.
To manufacture such a cushion, the buttocks - preferably when not subjected to a load - need to be measured and specified in such a way that the shape can be reproduced in the cushion. Usually the shape obtained from this measurement process is cut into a section of foam which is then placed on a flat surface.

It is not within the scope of this survey to examine and compare the various commercial methods and models which exist for this group of cushions.
As an extension to the experiments carried out on the test buttocks' mould used as a support structure (section 3.1.1), a manufacturer was approached and asked to produce a custom contoured seat for the test buttocks using his own specific technique. The manufacturer was provided with a wooden model of the test buttocks for this purpose. On the basis of measurements a robust piece of foam was cut out to correspond to the shape of the test buttocks including the anal cleft. To complete the cushion, the foam, being flat on the underside, was given a stretch cover.
Initially the cushion was tested on a flat board according to the manufacturer's specifications. The result was disappointing with a PDQ of 52 and a maximum pressure of 214 mmHg.
In consultation the manufacturer's original support structure was used for the test - a flat sheet of thin polystyrene which sagged about 1 cm when subjected to a load. Compared to the initial tests the difference was considerable with the maximum pressure under the central tuberosity decreasing from 214 to 98 mmHg, the EF climbing to above 0.8 and the PDQ rising to 79.
The results of this exercise are shown in table 5-3.

The improvement in PDQ when compared to the initial test might be explained by the sag observed in the polystyrene support. This sagging means that the sides of the cushion are pushed towards each other when subjected to load, helping to absorb some of this load. This relieves pressure on the tuberosities, thus improving the result. The deformability of the support structure therefore has an 'active' influence on the pressure-distribution of the cushion.
For the second test a pressure reading of 106 mmHg was taken for the B5 test cell on the coccyx. The cushion is an accurate imprint of the test buttocks with the anal cleft forming a sharp rise in the centre of the cushion. Evidently, it has such an effect on the results.

	PDQ	PD	EF	E1	E2	E3	E4	max. pressure mmHg
Test buttocks in own mould	69	73.5	0.755	0.941	0.899	0.662	0.709	153
'Custom contoured seat' in own supp.struct.*	79	75.0	0.838	0.942	0.894	0.912	0.709	98**
'Custom contoured seat' on flat board	52	63.6	0.658	0.977	0.867	0.496	0.612	214

* sags by about 10 mm.
** max. pressure on coccyx is 106 mmHg as a result of reproduction of anal cleft.

Table 5-3 : The influence of the support structure on the pressure-distribution result of a 'custom contoured seat' system, compared with test buttocks in own mould.

The results shown above demonstrate the effectiveness of the custom contoured seat in terms of pressure-distribution. In passing it should be noted that to attain a good result (i.e. by using the cushion correctly) some preconditions are necessary. After all, in real life situations these types of cushion are used primarily to offset asymmetry in the buttocks.
To realise an effective level of pressure-distribution on a daily basis, it is important that the individual is able to follow a number of simple rules when sitting down. Accurate positioning of the buttocks in the cushion is a prerequisite for obtaining good results. It will become evident that, when this procedure is not followed, the system will start to work against itself. In that case the remedy may be worse than the disease.
Neither should the effects of clothing in term of thickness and close-fitting be underestimated.

Another problem is how, if possible, the custom contoured seat can be optimised. Chapter 3.0 dealt with two phenomena, namely the influence of the relative deformation of the foam and the influence the support structure's shape which might be improved, using the manufacturing method described above. If we apply the theory which has been developed, it is evident that a custom contoured seat will have to be constructed around a 'custom contoured' support structure, taking into account the shape of the buttocks minus the foam layer thickness. By doing this, the relative indentation of the foam will be equalised, no longer being at its most extreme under the tuberosities as in the model described earlier. The attributes of the foam (e.g. rigidity) need to be matched to the buttocks in such a way that the contours, measured from the buttocks, develop in the support structure when subjected to load. By choosing a slightly less rigid foam than for the rest of the cushion in the area under the tuberosities, the rest of the cushion will be able to absorb relatively more load than the tuberosities. This will help improve the effectiveness of the pressure-distribution yet further.

It will be clear from the considerations given above that custom contoured seats may well possess high levels of effectiveness, but the realisation of this in practice remains critical. For extremely asymmetrically shaped buttocks as well as for asymmetrical deformations of the body, custom contoured seats together with custom contoured body supports appear to be the prescribed formula for realising a good support for the body.

In general support structures with a good level of deformability are preferred, since this kind of system is more able to react to small alterations which occur in daily situations.

5.3 The pressure-distribution quality of air- and liquid-filled cushions

The principal differences between foam cushions and their air- and liquid-filled counterparts have been discussed in the analysis in chapter 3.0. The air or hydrostatic pressure present in the cushion system is dependent on the size of the load in relation to the size of the surface area under load. The latter is dependent on the amount of air or liquid which is present in the system. It was shown that, as regards the magnitude of pressure-distribution measured, there are no principal differences in the pressure-distribution properties of air, water or other more viscous liquids. The way in which the tensile stress in the surface under load, that is the tensile stress in the casing, is dealt with, is however influential. It can be assumed that there is a direct connection between the amount of air- or hydrostatic pressure and the tensile stress which develops in the casing.

The results for liquid gel cushions are listed in table 5-4 and likewise for air-filled cushions with a single casing in table 5-5.
On the basis of the aforesaid considerations the results for these two types of types of cushions should show the same order of magnitude in pressure-distribution.

	PDQ	PD	EF	E1	E2	E3	E4	max. press. mmHg
JAY Medical liquid gel on contoured shell	71	68.2	0.829	0.998	0.931	0.634	0.922	184
JAY ACTIVE on contoured shell	59	63.5	0.749	0.979	0.820	0.723	0.704	181
Thera-flo liquid gel (hammock)	64	69.5	0.742	0.995	0.846	0.712	0.667	163
ZeroG (thin) liquid gel (hammock)	57	66.4	0.687	0.990	0.784	0.748	0.528	187
ZeroG (thick) liquid gel (hammock)	59	66.9	0.680	0.983	0.793	0.726	0.521	181
Aquamed liquid gel (hammock)	57	65.3	0.692	0.993	0.792	0.723	0.562	184

Table 5-4 : The pressure-distribution quality (PDQ) of liquid gel cushions

	PDQ	PD	EF	E1	E2	E3	E4	max. press. mmHg
Bye-Bye WS hammock	78	81.4	0.766	0.968	0.932	0.600	0.766	125
Bye-Bye WL hammock	72	77.7	0.743	0.915	0.841	0.835	0.554	133
Waffle WCP hammock	66	70.5	0.753	0.974	0.831	0.757	0.672	152
Varilite (air + foam) pre-contoured shell on hammock	63	66.5	0.746	0.998	0.819	0.809	0.610	172
Vacuum cushion on hammock (air + foam) (40 mm thick)	58	64.9	0.712	0.947	0.825	0.714	0.596	191

Table 5-5 : Pressure-distribution results for air-filled cushions and air-foam cushions with single casings

The pressure-distribution (PD) of liquid gel cushions show similar values (between 63.5 and 69.3%). The same is true of maximum pressure with 5 values slightly higher than 180 mmHg. These values closely match those of the Varilite and the Vacuum cushions which had PD values of 66.5% and 64.9% and maximum pressures of 172 mmHg and 191 mmHg respectively.
These values evidently represent the upper limit of water- and air-filled cushions when the shape of the casing is not influenced. If, however, this is

taken into account, as for the Bye-Bye and Waffle WCP cushions, an improvement in PD to 81.4 % is possible. These cushions incorporate spaces in the area of the tuberosities, which in their inflated state not only influence the shape locally, but also the tensile stress in the surface under load.

Moreover the Bye-Bye and Waffle cushions appear to be very sensitive to the repositioning of the buttocks. By moving the test buttocks 2 cm forwards, a change is found in PDQ from -50 for the WS type cushion, +8 for the WL type cushion and 0 for the Waffle. From these figures it can be concluded that what can be considered to be an optimum level of air in the cushion, depends partly on the positioning of the buttocks on the cushion. The deterioration of -50 PDQ can only be caused by a sort of 'bottoming out', whereby the layer of air between the buttocks and the support structure disappears.

The Jay Medical cushion consists of a pre-contoured shell which has an opening at the rear and a thin layer of viscous liquid, contained within a flexible casing. The casing is divided into a number of sections which are connected to each other. The area around the tuberosities comprises one compartment, and the support to the thighs is divided into four compartments along their length. There is a partition between the right and left hand sides of the cushion. The dimensions of the cushion are meant to match the dimensions of the user. The manufacturer does indeed caution the user about the problem of bottoming out. This is a phenomenon whereby the pressure-distribution layer becomes so thin or is squeezed out to such an extent, as is the case with foam as a pressure-distributing medium, that the pressure-distributing medium is lost.

In a study carried out on 163 elderly persons with a high decubitus risk the effectiveness of the Jay Medical cushion and the foam cushion used appeared to differ significantly (Conine 1994). The foam cushion used for this survey consisted of a polyurethane foam with a mass of around 32 kg per m^3 and a thickness at its centre of 10 cm, decreasing to 5 cm on the outside and placed on a hammock support structure. The foam compensates, as it were, the sagging of the hammock, in order to prevent seat sling. Both cushions used the same covers comprising a thin and open polyester fabric.
The difference between both cushions was that, for the group of test subjects using the Jay cushion, 25% contracted decubitus whilst this was 41% for the foam cushion. Users showing an interface pressure of more than 60 mmHg under the tuberosities and with a high decubitus risk or a poor dietary condition, showed a greater prevalence of decubitus.
An interface pressure of lower than 60 mmHg is attained for cushions with a PDQ value above 90 on the basis of comparisons with Bar's results (see figure 4-14, section 4.5.1). This is the target level which has been established for the high-risk user cushion.

The PDQ of the Jay Medical cushion used was 71. The PDQ of the foam cushion developed was estimated at between 50 and 60. Conine's results can be considered as further confirmation of the assessment criteria which have been established. It can also be noted here that the group of test subjects show a high decubitus risk and therefore the test buttocks, given the results, can also be considered to be critical.
The experiments carried out into the influence of the thickness of the foam and the influence of the support structure on the pressure-distribution results confirm that the 'filling in' of the sagging of the hammock (as described before) is contra-effective for the pressure-distribution. The foam used has a mass which is similar to the mass of the foam used in the experiments. The relative deformation of the foam under load will be high both in the centre and the outside.

The Jay Active cushion is a similar cushion with liquid gel pads only under the tuberosities and not under the thighs. The cushion which was tested was 40 mm wider than the Jay Medical cushion.
The eventual magnitude of the PDQ for this cushion was determined largely by the size of the EF. The pre-contoured shell of the Jay Medical cushion seems to have a beneficial effect on the size of the surface under load and on the equality of the pressure-distribution. The splitting up of viscous fluid in a number of small sections also makes a contribution to this. It is interesting to note what exactly the effects are of the EF on the eventual PDQ for different cushions which have roughly the same maximum pressure values.

The Varilite and the Vacuum cushions have casings in which foam is incorporated. Under the influence of deformation the foam contributes to the reaction forces, which result form the load being applied. This leads to a situation in which the air pressure in the system might be lower than without the foam. This means a reduction in tensile stress in the casing. Unfortunately, this survey was unable to measure the air pressure in these systems accurately when under load so that a presentation and analysis of data proved impossible.

The tensile stress in the surface area under load can be influenced by dividing the surface area into a number of smaller surfaces, so that no tensile stress can develop in the surface as a whole. This phenomenon was dealt with in chapter 3. The separate cells which make up the complete surface area are connected to each other. The tensile stress, which results from air pressure developing in the casing in theory is, the same as for cushions where the casing consists of one single cell. Since the sling seat effect is no longer present, conformity with the buttocks will be achieved much more easily, thus enabling better pressure-distribution.
Table 5-6 summarises the results recorded for air-filled cushions of which the casing consists of several cells.

	PDQ	PD %	EF	E1	E2	E3	E4	max. pressure mmHg
Roho 1R 89. SP*								
- hammock	80	73.5	0.871	0.941	0.891	0.851	0.871	136
- flat board	91	82.8	0.883	0.999	0.917	0.895	0.838	91
Roho 2R 89*								
- hammock	89	79.6	0.892	0.992	0.903	0.915	0.858	90
- flat board	76	76.0	0.795	0.959	0.870	0.775	0.740	129
Roho 2R 89 Paracare*								
- hammock	64	67.5	0.759	0.995	0.752	0.993	0.532	176
- flat board	55	66.0	0.663	0.965	0.770	0.734	0.484	194
Bellows Air Flotation								
- hammock	68	71.0	0.760	0.987	0.820	0.838	0.621	145
Bellows Air Sequential Pressure								
- hammock after 60s	64	67.0	0.765	0.976	0.752	0.929	0.614	190
after 120s	68	68.6	0.792	0.956	0.759	0.845	0.772	146
after 180s	68	69.3	0.781	0.993	0.794	0.912	0.636	165
after 240s	63	67.1	0.750	0.986	0.777	0.858	0.616	185
after 300s	62	65.1	0.755	0.988	0.754	0.926	0.586	190
after 360s	62	64.9	0.758	0.931	0.729	0.968	0.578	191

* tested with met cover

NB Roho 1R89. SP : 8 x 9 balloons (l x br)
Roho R 89 : 9 x 8 balloons (l x br)

Table 5-6 : Results of pressure-distribution quality (PDQ) of air-filled cushions where surface under load is divided into smaller compartments.

The Bellows Air cushion differs from the Roho air-filled cushion in the fact that its air cells are embedded in foam. The cells are shaped in such a way that they deform in a predictable manner, subsiding vertically into the foam. The simultaneous deformation of the foam will contribute to the reaction forces as a result of the load. On the other hand the surface of the air cells when under load is smaller in total, since the cells are not linked to each other (as opposed to the Roho cushion where the surface of each cell is directly adjacent to the next one). As a result the air pressure for the Bellows Air cushion system will be higher for an evenly loaded surface, thus leading to a lower pressure-distribution.

The results for the Roho cushions differ somewhat. The current survey did not systematically examine the influence of the different parameters on the eventual pressure-distribution results. Neither was this within the scope of the survey.

However, a number of experimental tests were carried out, in order to gain a better understanding. These did not lead to any significant conclusions. What was clear however was that the amount of air in the system, the way in which deformation takes place and the use of a cover are determining factors in respect of the eventual pressure which develops in the system and in turn the final results.

The Roho paracare is a cushion in which the contours of the buttocks are reproduced in the height of the cells. The cells directly under the tuberosities are the lowest and their deformation is negligible and therefore more predictable. The volume of the cushion, when not subjected to a load, is however considerably smaller than for the other model, where the cells are higher. In practice this means that it is still possible to attain exactly the right amount of air, that is, the correct indentation in the cushion. Were the air pressure in Roho cushion to be at 28 mmHg, this would be about 40 mmHg for the Roho paracare cushion. The overall results for the paracare cushion are lower than for the rest of the Roho cushions.

Krouskop (1986) examined the relationship between the air pressure and the interface pressure under the tuberosities using a total of 14 test subjects (7 physically able and 7 with a spinal cord lesion). Three different air-filled cushions were tested: the Roho cushion, the Bye-Bye Decubiti cushion and the Gaymar Sofcare cushion. This latter cushion, which was not included in the current survey, is a 'mattress' type cushion whose upper half of the cover is attached to the lower half in a certain pattern. Krouskop's study revealed that there is only a small level of correlation between body-weight, body-build and interface pressure. The area, within which the air pressure of the cushion is located and which gives an optimum interface pressure, appeared to be small, being only 6 to 8 mmHg. An air pressure which is too low is more critical than one which is too high. The effective air pressure in the cushion observed by Krouskop for his 14 test subjects was 35 mmHg. No data relating to a comparative analysis of the different systems is included in Krouskop's article.

Table 5-6 also includes the results for the Bellows Air Sequential cushion. The 'Bellows sequential air pressure relief cushion' appears to be programmed in such a way that every five minutes the air pressure is reduced for a period of one minute or so, in turn for each of the 4 rearmost rows of cells under the tuberosities. The pressure registered in the B2 sensor ranges therefore between 145 and 194 mmHg. The PDQ fluctuates between 62 and 68. In preventing decubitus, the system aims to facilitate the circulation of fluids in the vascular system by way of the cushion's massaging action. A definitive verdict on the effectiveness of such a system cannot be made in this survey.
Bader (1990) examined the influence of alternating interface pressure on the transcutaneous oxygen pressure (PO_2) for this particular cushion. The oxygen

pressure gives no indication of the condition of the tissue. Bader found that for healthy persons the oxygen pressure was restored gradually in four load cycles, initially showing, however, an enormous fall in pressure after being subjected to a full load. For a 30 year old male with a spinal cord lesion an almost constant interface pressure of 38 mmHg was recorded under the tuberosities. The oxygen pressure for this test subject was restored in a normal fashion after an initial fall in pressure. For another 22 year old male with a spinal cord lesion the oxygen pressure was not fully restored by the alternating pressure. By lifting for a period of about 90 seconds the oxygen pressure level was restored to its original level in two cycles. Lifting must have taken place at intervals of 5 to 7 minutes, in order for the condition of the tissue to be maintained. On inspection these test subjects showed a considerable level of erythema on the buttocks. Bader drew the conclusion from these results that an active vasomotor response mechanism is evidently necessary, in order to restore the oxygen pressure level. If this is not present, the temporary pressure reduction in this particular cushion is insufficient to enable recovery of the oxygen pressure level in the tissue.

In order to gain an impression of the reproducibility of the test results for this type of cushion, repeat tests were carried out on two Roho cushions over a number of days. The results of this exercise are listed in table 5-7.
During the tests the amount of air in the system remained unchanged. The distance, between the test buttocks and the underside of the cushion when subjected to a load, was about 17 mm.

The difference between the two cushions is that one was tested along its length and the other across its width. Further examination of the results will reveal that a slightly higher pressure in the system does not necessarily lead to poorer pressure-distribution (PD) and that the equality factor (EF) has an important effect on the eventual result. The best average is achieved at low pressures. A general conclusion, however, cannot be made in respect of this, since, as was explained earlier, the pressure in the system cannot be measured with any great accuracy. The PDQ in the repeat tests on the Roho cushions shows a higher SD than was found for the pre-load cushion, whose SD was on average 1.2 for 3 periods of 3 to 4 months. Even under laboratory conditions which can be closely monitored it appeared difficult to match the result obtained for the Roho cushion. A wider range of values would, however, be expected when the cushion is used in daily situations, thus reducing the reliability of this system.

	PDQ	PD	EF	E1	E2	E3	E4	max. press. mmHg
Roho 2R89 8 wide, 9 long n = 7								
mean	79.7	73.9	0.863	0.976	0.813	0.947	0.828	113.6
SD	2.6	2.1	0.025					16.1
	NB : hip value B8 mean 63.5 mmHg air pressure in the system about 27 mmHg							
Roho 1R89 SP 9 wide, 8 long n = 4								
Mean	72.6	76.7	0.757	0.942	0.817	0.770	0.683	136
SD	1.8	0.9	0.012					8.8
	NB: hip value B8 mean 60.5 mmHg air pressure in the system about 30 mmHg							

Table 5-7 : Repeat tests on the Roho cushion.

5.4 The pressure-distribution quality of non-fluidised gel cushions

Table 5-8 summarises the results obtained for non-fluidised gel cushions. The potential of this system for pressure-distribution is evidently limited and certainly more limited than the manufacturer's claims would have us believe. The shape of the hammock would appear to have the most significant influence on the results for these cushions. PDQ values of 13, 22, 23 and 18 were measured for these cushions when placed on a flat board.

Non-fluidised gel is in many ways simular to soft tissue in the buttocks. If a cross-section of a model of a pair of buttocks is made, in which DRAKA 9018 foam is used to represent the softer tissue, and hard plastic is used to replace the pelvis, and when this model is then placed with a small load on the same foam used as a cushion, it can be observed that the foam under the tuberosities in the model will show much more deformation than the foam in the cushion. This is also what happens when a non-fluidised gel cushion is subjected to a load by the test buttocks.
A high level of maximum pressures was registered for these cushions.

	PDQ	PD %	EF	E1	E2	E3	E4	max. pressure mmHg
Action AD-cushion 5200 (35 mm thick)	45	57.8	0.629	0.998	0.750	0.650	0.486	238
Action AD-cushion 5100 (50 mm thick)	42	54.1	0.625	0.979	0.758	0.564	0.552	251
Secutex	45	55.2	0.649	0.984	0.754	0.612	0.582	241
Reston Flotation Pad	44	53.4	0.605	0.950	0.743	0.559	0.512	252

Table 5-8 : Pressure-distribution results for non-fluidised gel cushions, tested on hammock.

5.5 The pressure-distribution quality of fibre and hybrid cushions

Cushions which are filled with hollow siliconised fibre provide a special category of cushions but they work more or less according to the assumed principles encompassed in the four questions formulated earlier. Fibre can be considered to form a material which has an open structure and a particular density. A link between indentation and the reaction forces will be present similar to that in foam cushions. This relationship will depend partly on the nature of the fibrous structure. The cushions in this survey had the feel of a soft foam material. The support structure therefore will have an important bearing on the pressure-distribution for these cushions.
Table 5-9 gives the results for these cushions.

	PDQ	PD	EF	E1	E2	E3	E4	max. press. mmHg
Polycore cushion with wool layer	77	76.5	0.802	0.951	0.914	0.828	0.662	136
Medicore cushion	40	56.9	0.569	0.910	0.782	0.482	0.443	283
Polyfibre	64	64.0	0.803	0.954	0.780	0.961	0.667	189
Spenco silicore	53	61.8	0.683	0.990	0.760	0.743	0.546	217

Table 5-9 : Pressure-distribution quality of cushions filled with fibre, measured on a hammock.

The Polycore cushion on a flat board registers a PDQ of 46. The layer of wool probably has a positive effect on the PDQ. Section 5.6 discusses the effects of a sheepskin material on pressure-distribution. No experiments have been carried out which examine the parameters of sheepskin influencing the pressure-distribution.

The pressure-distribution results for hybrid cushion systems are listed in table 5-10. Two of the cushions consist of a combination of foam, fluidised gel and foam. The results are not exactly spectacular when compared to those recorded for the foam experiments. The gel components will almost certainly influence the heat regulation.

	PDQ	PD %	EF	E1	E2	E3	E4	max. press. mmHg
Spenco-toilet model hydrofloat	83	85	0.779	0.858	0.936	0.643	0.757	143*
Halifax Care cushion foam/fluid. gel/foam	59	65.7	0.723	0.980	0.825	0.745	0.600	193
Bay Jacobson foam + T foam	69	72	0.770	0.972	0.839	0.806	0.665	149
Charnwood LDC foam/fluid.gel/ foam	68	71	0.757	0.988	0.822	0.861	0.588	140

*B9 'top of thigh bone' = 143 mmHg
B3 'behind tuberosity = 83 mmHg
B2 'middle tuberosity = 42 mmHg
B1 'in front of tuberosity = 30 mmHg

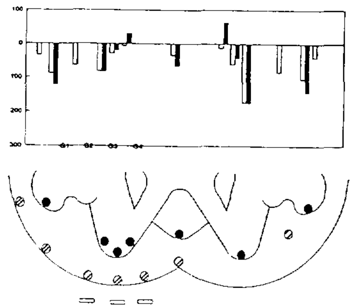
Table 5-10 : Pressure-distribution quality of hybrid cushion systems, measured on hammock.

The Spenco Toilet model is not really a hybrid but offers a special solution. It consists of a ring of non-fluidised gel with a thickness of 60 mm, contained within a cover and it looks similar to a toilet seat. The cushion shows interesting pressure-distribution characteristics, since the readings are taken internally directly underneath the tuberosities despite the fact that the buttocks are suspended, as it were, in thin air. The skin which is attached to the outer ring of the cushion serves as a support structure for the softer parts of tissue under the pelvis. The soft tissue forms the pressure-distributing medium for the pelvis which transmits the load of the upper half of the body to the skin. A pressure reading of 83 mmHg was measured in the sensor B3 behind the tuberosity. Since a relatively large difference was found between the symmetric sensors B2 and B4, which might be caused by a non-symmetric load, the graph presented in figure 5-1 looks slightly lop-sided. The highest pressure was recorded at the top of the thigh bone (143 mmHg). This value cannot be used in the formula for pressure-distribution (PD), but can be used in formula for the equality factor. The PD calculated is 85%. This is the highest value recorded in this survey. The EF calculated is 0.799 and is above the overall average of 0.702 for the survey as a whole. For comparison the Kubivent R 102 results are included. This particular cushion has one of the highest recorded EF values in the survey.

Spenco toilet model
measured on hammock

PDQ : 83
PD : 85.5 %
EF : 0.799

max. pressure in B8: 143 mmHg
pressure in H2: 29 mmHg



Kubivent R 104
measured on hammock

PDQ : 77
PD : 70.2 %
EF : 0.874

max. pressure in B4: 138 mmHg

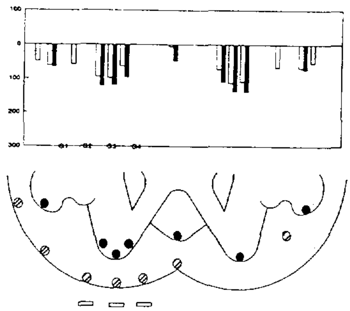


Figure 5-1 : Representation in graph form of the pressure-distribution results for the Spenco toilet model cushion.

For this particular test the test buttocks provide proof of their specific qualities. No other known method has been used to measure the pressure-distribution of this type of cushion. The test results for this cushion give a special insight into how pressure-distribution in the buttocks develops. The influence of skin properties on pressure-distribution in particular can be better understood using this method of testing. A weakening of the skin under the tuberosities by softening will result in the tensile strength of the skin being reduced and in increasing strain whereby the tuberosity will start, as it were, to stab at the skin. This will lead to high pressures.

5.6 The influence of synthetic sheepskin on pressure-distribution

Cushions which lack water vapour absorption properties are often provided with sheepskin covers, to increase overall comfort and to improve the moisture regulating properties of the system. In cases where incontinence is present the cushion can be washed or wiped clean and the sheepskin also washed or possibly replaced. Synthetic sheepskin is usually used for this purpose.
In order to examine the influence of fleece on pressure-distribution and the heat- and moisture-regulating capacities of cushions, a number of tests were carried out to complete the cushion survey. These tests were performed at the same time as tests, that looked into the influence of the size of load on the pressure-distribution.
This section describes these tests.

The sheepskin used had the following specifications:

material	: polyester
basis	: knitted
weight	: 12.075 gram/dm^2
thickness	: 15.7 mm (at 30 mmHg pressure)

The pressure-distribution was measured using three different cushions at three different loads: 500 N, 600 N and 700 N.
Two of the cushions had a pvc-vinyl cover.
On the basis of 9 tests the pressure-distribution quality (PDQ) when using the sheepskin was increased on the average by 9.66 with an SD of 3.80. The results are shown in table 5-11.

The increase in PDQ appears to be caused for a large part by an increase in EF. This rises on average by 9.7% (SD=2.67), whilst the PD rises on average by 5.1% (SD=6.4). This calculation includes an extreme reading of -10%. If this reading is ignored (n = 8), the mean is 7.1 % with an SD of 2.94. The unwashed synthetic sheepskin fleece, which was used for the tests, improves the pressure-distribution quality quite considerably.

	load	PDQ without sheepskin	PDQ with sheepskin	difference PDQ
Foam + fabric on hammock	500 N	78	79	1
	600 N	67	76	9
	700 N	60	72	12
foam rubber + vinyl on webbing	500 N	58	72	14
	600 N	55	68	13
	700 N	52	62	10
coconut fibre + vinyl on trampoline	500 N	75	83	8
	600 N	72	83	11
	700 N	70	79	9

Mean increase = 9.66
SD = 3.80

Table 5-11 : Influence of synthetic sheepskin on the pressure-distribution quality (PDQ) for different types of cushions at different loads.

A list of the results is given in table 5-12 for the same sheepskin fleece, when washed and left unbrushed, and for a much thinner fleece with a thickness of 5 mm at 30 mmHg load.

	PDQ	PD	EF	max. pressure mmHg
cushion: 6 cm foam rubber on webbing + vinyl cover				
without sheepskin	55	65.7	0.665	194
with sheepskin	68	71.3	0.762	150
with washed sheepskin and unbrushed	59	69.2	0.684	191
with thin sheepskin	51	64.1	0.640	212

Table 5-12 : Influence of various synthetic sheepskins on the pressure-distribution quality (PDQ) for one cushion fitted with pvc-vinyl cover.

The washed fleece increases pressure-distribution quality but not greatly. The thinner fleece shows a decrease in PDQ. This sheepskin fleece had a stiff woven structure with a rough texture. This might produce a hammock effect, given the low EF.

The conclusion made here is that the synthetic fleece can increase the pressure-distribution quality, as long as the fleece is sufficiently thick and has a pliant structure.

5.7 Summary and conclusions

The pressure-distribution characteristics of different cushion systems can be explained on the basis of the four following questions:
-To what extent does the support structure contribute to the conformity with the shape of the buttocks? In other words, to what extent will the pressure-distributing medium be indented, or - in the case of foam - what level of relative indentation will be produced?
-What is the link between the indentation and reaction force of the pressure-distributing medium being used?
-To what extent does an (undesirable) tensile stress develop in the surface under load in its entirety and what is the influence of the cover on this phenomenon?
-Is the pressure-distribution medium capable of reducing localised reaction forces under the ischial tuberosities?

With the exception of the non-fluidised gel cushions it would appear possible to attain reasonable results with the different systems.
Each of the categories tested have cushions with a PDQ of more than 65. Compared to the results, attained using the foam (80 mm foam on trampoline with a PDQ of 78), the pressure-distribution qualities of many cushions, including the so-called AD cushions, are quite disappointing. Of the 71 cushions tested only 4 cushions have an equal or higher PDQ. Air-filled cushions, whose surfaces are divided into smaller compartments, do indeed come up to their pressure-distribution reputations in the survey. The realisation of these results, however, is linked to the critical preconditions.

When the results of the pressure-distribution quality of the different cushions are equated with the target levels specified for the different user groups, then the following picture is revealed (table 5-13)

These results do not represent an unqualified success. Bearing in mind the four questions, it must be a relatively simple exercise to improve the cushions. Chapter 7 discusses the results of the experimental cushions and explores a number of different approaches.

To complete this chapter the 12 cushions with the best pressure-distribution qualities are listed in table 5-14.

	threshold level PDQ	meets threshold value PDQ	target level PDQ	meets target level PDQ
	PDQ	number	PDQ	number
low-risk user cushion	≤ 45	52	≥ 60	28
medium-risk user cushion	≤ 55	41	≥ 65	17
high-risk user cushion	≤ 65	17	≥ 75	6

Table 5-13 : Results of cushion survey in relation to target levels of pressure-distribution quality (PDQ) for the different user groups (n = 71).

name	cover	pressure distr. medium	support struct.	PDQ	PD %	EF	max. pressure mmHg
Roho 1R89 HP	thin fabric	air cells	flat board	91	83	0.883	91
Spenco toilet model	fabric	non-fluid. gel	hammock	83	85	0.779	143*
BYE-BYE type WS	rubber	air	hammock	78	81	0.766	125
Kubivent R 104	thin fabric	foam blocks 100 mm high	hammock	77	70	0.874	138
Polycore with wool layer	fabric	fibre	hammock	77	76	0.802	136
BYE-BYE type WL	rubber	air	hammock	72	78	0.743	133
JAY Medical	folie	viscous liquid	contoured shell on flat board	71	68	0.829	160
Etac for Swede F3	fabric	polyether foam 60 mm	hammock	70	73	0.767	143
Bay Jacobson	fabric	foam + visco-elast.foam	hammock	69	72	0.770	149
Bellows Air Flotation	fabric	air, many cells in foam	hammock	68	71	0.760	145
Uniblok	stretch	foam, cut	hammock	68	65	0.829	167
Charnwood LCD	nylon coated	foam/gel/foam	hammock	68	71	0.757	140

* see also figure 5-1

Table 5-14 : Summary of the pressure distribuing quality: PDQ of top 12 commercially available cushions.

6.0 Analysis of other cushion characteristics

Although pressure-distribution is considered to be the most important property of a wheelchair-cushion, there are a number of other characteristics, which not only have a bearing on the perception of comfort, but also might contribute to the prevention of decubitus. These were discussed in section 1.4. Some additional characteristics may go towards creating favourable conditions for sitting down, i.e. the transfer and for adopting a good sitting posture. Other cushion attributes might be mentioned, for example, concerning upkeep, durability, reliability and safety.
Sections 1.4 and 2.3.2 referred to sitting stability and heat- and moisture regulation as important cushion characteristics.
This chapter gives a short analysis of the relationship between the different cushion characteristics and the design of the cushion. In general a cushion comprises four layers:
-the cover
-the top layer
-the pressure-distributing layer
-the support structure

The top layer has been added bearing in mind the analyses of how pressure-distribution works in chapters 3 and 4.
These layers are not always physically present in a cushion.
However, this categorisation of cushion components enables not only a closer analysis of pressure-distribution, but also the 'positioning' of other important cushion attributes, which in turn can be interpreted and influenced.
The selection and relevance of wheelchair-cushion characteristics has been established on the basis of discussions carried out with therapists and other experts and by the enlistment of the wheelchair-cushion panel. This panel of experts played an important role in defining the assessment criteria and the relative importance on the different properties in relation to each other. Section 4.5 discussed the way in which the panel determined these assessment criteria for the pressure-distribution quality.
In section 6.1 other characteristics of cushions will be discussed on the basis of the description of the function of each of the different layers. In this respect these attributes acquire a functional relationship seen in terms of the cushion design, which provides an important starting point for designers. A short definition and relevance for each characteristic will be given in section 6.2, on the basis of a functional classification made in relation to the user and the therapist. Section 6.3 describes the evaluation of these characteristics in weighted order of importance and then gives a presentation of the findings.

The ensuing sections will deal with the test results in respect of a number of important characteristics.

6.1 Analysis of cushion characteristics

On the basis of certain desirable characteristics the different component layers of a cushion can be analyzed satisfactorily in respect to their influence on the different attributes. The extent to which a characteristic should be realised is related to the characteristics of the different user groups. Furthermore the question remains if all the desired characteristics can be attained simultaneously in one single cushion, or whether certain properties cancel other ones out. The results of the survey in relation to this question will be discussed in chapter 8.
The analysis of cushion characteristics takes the form of a description of desirable characteristics of each of the separate component layers of a cushion and their influence and contribution, beginning with the cover.

The cover consists of a robust smooth fabric which is crease-resistant when an individual sits down or is seated. This cover must be capable of contributing to *precise conformity*, that is, the capacity of the supporting medium to adapt itself to the contours of the buttocks and clothing.
A measure of this is the *surface softness*.
To attain good *surface softness* a slight local deformation under load must be possible. The tension in the cover when subjected to load should not be too high. For this reason the so-called 'hammock effect' needs to be avoided.
On the other hand, as has already been stated, no *creasing* should take place when the individual sits down. In principal the cover should be *permeable to moisture* to enable a satisfactory level of moisture regulation.
If the cover is permeable to moisture or water vapour, it should be *removable* as well as *washable*.
In all cases the cover should be *fire-resistant* and *resistant to urea*.
The cover should be sufficiently *wear-resistant*.

The layer directly under the cover, the *top layer*, is also instrumental in achieving *precise conformity*. In addition, the top layer has a significant role to play in *moisture and heat regulation*: out of necessity the structure of the top layer needs to be open and remain open when under load. It is conceivable that vertical movements of the cushion, due to shifts in posture or driving manoeuvres, bring about a kind of pumping action in the cushion, which forces out air into this open structure at the same time sucking in new air. In this way heat and moisture can be regulated in an 'active' fashion.
If the top layer is responsible for *moisture control* in cases of incontinence, it

should be possible to remove and replace it. In such cases the pressure-distribution layer should be non-permeable to moisture as well as *wipable.*

The pressure-distribution layer or cushion filling is responsible together with the support structure for the *general conformity*. The more easily this can be achieved, the better the pressure-distribution. It is to be recommended that deformation of the pressure-distribution layer is small and/or goes together with small reaction forces.
The pressure-distribution layer is also responsible for the way in which the friction forces are transmitted to the seat plane as a result of a poor sitting posture; this is referred to as the cushion's *consistency of shape*. When the upper side of the cushion shifts under load in relation to its underside, a good sitting posture will be prevented from being realised, since the pelvis will be tilted backwards as a result of the tuberosities sliding forwards. A satisfactory lumbar support cannot be achieved in this fashion.
The pressure-distribution layer, together with the support structure has an important role to play in the *shock-absorption capacity*. Since most wheelchairs do not incorporate a suspension system, this is an important characteristic.
The pressure-distribution layer, likewise together with the support structure, is primarily responsible for providing *sitting stability*. It is important, however, that the indentation on the left and right-hand side is equalised, when the load once again becomes symmetrical.

As has already been stated, every cushion requires a support structure, in order that the load can be transmitted to the wheelchair frame. Two systems can be identified:
- the non-deformable support structure: board, pre-contoured shell and hammock, or
- the deformable support structure: a non-deformable narrow outer ring in which a deformable structure is fitted. The structure may or may not be springy and comprise either webbing, no-sag springs or a trampoline.

The support structure has an enormous influence on the way in which conformity is achieved and on the degree of indentation in the pressure-distribution medium, necessary for this conformity to be realised. This was illustrated in sections 3.2.1 and 4.3. A well-sprung, deformable support structure will have a positive influence on the shock-absorption capacity.

6.2 Review of cushion characteristics

The above description of how a cushion works mentions a large number of cushion characteristics. This section will list the different characteristics examined in the survey, using a functional classification. A definition of each of these characteristics will be given together with a short summary of their relevance. For a description of the testing methodology reference is made to the book 'Voorstellen voor beoordelingscriteria voor rolstoelkussens' (Staarink 1993). In addition to putting forward proposals for assessment criteria in respect of wheelchair-cushions this book makes a number of suggestions with regard to changes in definitions, testing methods and processing methods. Section 6.3 presents a comprehensive analysis of the test results in respect of the six most important characteristics. A short description of the test method used is also given.

sitting characteristics
pressure-distribution quality (PDQ)
pressure-distribution (PD)
equality factor (EF)
surface softness
sitting stability
shock-absorption capacity

moisture and heat characteristics
moisture regulating capacity
heat regulating capacity

characteristics concerning sitting down/transfer
sacral indentation
frontal indentation
lateral indentation
longitudinal smoothness
transversal smoothness
consistency of shape
creasing

transportation characteristics
weight
portability
attachability

cleaning characteristics
washability of fabric cover
wipability of non-fabric cover
odour resistance
moisture control
wipability of cushion filling

durability
cover durability
cushion durability
age-resistance of cover
age-resistance of cushion

reliability
fill-ratio sensitivity
positioning sensitivity
influence of angle ϕ
vulnerability

safety
fire-resistance

6.2.1 Definition and relevance of characteristics

Characteristic: **Pressure-distribution Quality (PDQ)**

Definition: The pressure-distribution quality is a dimensionless number on a scale of 0 to 100, which represents the quality of pressure-distribution.
The pressure-distribution quality is the product of the pressure-distribution (PD) multiplied by the equality factor (EF) and expressed as a percentage of 80.

Relevance: A good cushion will have a high pressure-distribution (PD) and a high equality- factor (EF). (See definitions for PD and EF.)
In practice the product of PD and EF has a maximum of around 80 (90 * 0.9). By expressing the product of PD and EF as a percentage of 80, an evaluation scale is generated which enables a scoring system of 0 to 100.

Characteristic: **Pressure-distribution (PD)**

Definition: Pressure-distribution is defined as a percentage of a 600 N load which is taken up by the buttocks with the exception of the area around tuberosities (2 x 65 cm^2).
A pressure-distribution of 80% means that the areas around the tuberosities take up 20% of the load.

Relevance: The essence of pressure-distribution is that the areas around the tuberosities are relieved of load. The definition of pressure-distribution satisfies this requirement.

Characteristic: **Equality Factor (EF)**

Definition: The equality factor is the average of 3 pressure differences, measured between test sensors in a lateral section of the test buttocks as calculated at equidistant intervals of 25 mm and subsequently expressed on a scale of 0.4 to 1.0.

Relevance: The quality of the pressure-distribution is partly influenced by the equality of the pressure-distribution. Large variations in pressure can lead to deformations which result in undesirable internal reaction forces.

Characteristic: **Surface softness**

Definition: Surface softness is defined by the measure in which a surface under load can prevent an increase in pressure by localised, relatively small deformations.

Relevance: Double layered clothing may not lead to a local increase in pressure. This means that the cushion should deform instead of the buttocks.

Characteristic: **Stability**

Definition: Stability represents the cushion's capacity to maintain the pelvis in a roughly horizontal position, when the upper half of the body inclines to one or the other side.

Relevance: After pressure-distribution, stability is considered to be the most important characteristic. A cushion with little stability will not only be perceived as being uncomfortable, but can also have negative effects on the sitting posture.

Characteristic: **Shock-absorption capacity**

Definition: The capacity of a cushion to absorb extra load as a result of vertical impact.

Relevance: Shocks and vibrations, as a result of using the wheelchair on an uneven surface, should be absorbed in the best way possible so as to prevent an instable or erratic feeling when in a sitting position. In principle shock-absorption is a feature of the wheelchair and should be defined as such. Since most wheelchairs are not fitted with suspension, the shock-absorption of a cushion is considered to be extremely important.

Characteristic: **Moisture regulation**

Definition: The extent to which a cushion is able to process moisture resulting from transpiration.

Relevance: Moisture in the contact plane between the seat and the buttocks softens the skin, which can lead to decubitus. This also involves a loss of comfort.

Characteristic: **Heat regulation**

Definition: The extent to which a cushion is able to regulate temperature in the contact plane between the seat and the buttocks.

relevance: An increase in temperature is undesirable because of increases in cell metabolism. If the supply of oxygen and nutrients is reduced, then damage may result. A rise in temperature will also lead to more transpiration. For users with sensibility a temperature rise in the contact plane means loss in comfort, partly on account of increased transpiration.

Characteristic: **Sacral indentation**

Definition: The difference between the cushion's height, when it is placed under load, compared to when it is relieved of this load - measured under the tuberosities.

Relevance: Indentation is a phenomena which can facilitate or impede sitting down and transfer processes. The more a cushion is indented during sitting, the more difficult and the greater the distance necessary to raise oneself.

Characteristic: **Frontal indentation**

Definition: The difference in height at the front of the cushion when it is placed under a load, compared to when it is relieved of this load.

Relevance: The process of sitting down is an essential, critical and difficult task for a wheelchair-user. A high level of, as well as large differences in, indentation do not make this process any easier. Furthermore the cushion needs to offer a reliable temporary support during this transfer.

Characteristic: **Lateral indentation**

Definition: The difference in height at the sides of the cushion when it is placed under a load, compared to when it is relieved of this load.

Relevance: During a transfer the body is lifted and then rested momentarily on the edge of the cushion. The cushion should help facilitate this lifting and resting in a reliable fashion.

Characteristic: **Longitudinal smoothness**

Definition: The measure of resistance between the cushion and the clothing in a longitudinal direction during the sitting down/repositioning process. As a result the cushion is only partly subjected to load.

Relevance: This feature is connected to the sitting down and repositioning processes. Smoothness needs to facilitate these processes without introducing negative effects. The position of the clothing in respect to the body or skin should not be allowed to be displaced during transfer or repositioning so as to induce undesirable forces on the skin. This means that the friction coefficient between the cushion covering and clothes must be as low as possible. It is assumed that the transfer involves a small lifting action and that the cushion is subjected to a small load only.

Characteristic: **Transversal smoothness**

Definition: The measure of smoothness in the cushion, transversally, which has a bearing on transfer and/or repositioning. The cushion is only partly subjected to load.

Relevance: The 'smoothness' in the transversal plane affects the way in which a transfer or repositioning movement is made. In order to enable this without causing inconvenient side effects the cushion must be sufficiently 'smooth'. It is assumed that there is an element of 'lift' in the transfer process and therefore only a minimal load is placed on the cushion.

Characteristic: **Creasing**

Definition: Creasing occurs if the cover of the cushion folds double during the sitting-down process.

Relevance: A cushion should enable the user to sit down with or without having to move the buttocks backwards in a tilting movement. The cover should remain in place without any undesirable creasing occurring.

Characteristic: **Consistency of shape**

Definition: The horizontal shifting of the upper side of a loaded cushion in relation to its basic construction as a result of a shear force, arising from an incorrect sitting posture.

Relevance: A poor sitting posture produces a shear force in the sitting plane. A friction force develops in the seat as a response to this shear force. When these friction forces develop, the upper side of the seat may 'move' in relation to the under side of the seat. This shifting is undesirable, since the tuberosities slide forwards and the pelvis is tilted backwards, increasing load on the coccyx and causing a kyphosis of the lumbar spinal column.

Characteristic: **Weight**

Definition: The weight of the removable part of the cushion design.

Relevance: It is important, both for a manual as well as an electric wheelchair, that the total construction is as lightweight as possible. Furthermore with regard to its portability a lightweight cushion is easier to remove from the wheelchair.

Characteristic: **Dimensions**

Definition: The overall length, width and thickness of a cushion.

Relevance: The dimensions of a cushion are not only important for its general 'construction' but a cushion must also physically fit into a wheelchair. These dimensions can also influence the performance of the cushion, when related to the individual body measurements of the user, in situations where the cushion has a deformable support structure.

Characteristic: **Portability**

Definition: The ease with which the cushion can be picked up manually and carried separately.

Relevance: The foldability and portability of a wheelchair mean that the 'removability', i.e. the portability of a cushion is an essential requirement.

Characteristic: **Attachability**

Definition: The possibility of fixing a cushion in such a way that it cannot be displaced when the user is sitting down.

Relevance: Being able to sit properly, is a prerequisite for a correct sitting posture and to effectuate good cushion performance. In order to achieve this, the cushion must be positioned in the wheelchair correctly. The possibility of detaching the cushion from its fixture is recommended for the wheelchair's transportability.

Characteristic: **Fill-ratio sensitivity**

Definition: This defines whether the pressure-distribution performance of the cushion is dependent on the amount of pressure-distribution medium in the cushion (air, fluid etc) and whether or not this amount needs to be adjusted to individual user needs.

Relevance: If the individual must 'fine-tune' the pressure-distribution performance, the functioning of the cushion in day-to-day activities is critical. Imprudent use can have negative effects.

Characteristic: **Positioning sensitivity**

Definition: This is the extent to which the pressure-distribution quality of a cushion is dependent on the position of the user in relation to the rear side of the cushion. The positioning sensitivity is expressed in terms of PDQ values (either plus or minus) in relation to the results of the standard testing procedure.

Relevance: In clinical situations the user must position himself as carefully as possible on the cushion as well as in the wheelchair. For some cushions this positioning process is more critical than others.

Characteristic: **Influence of angle ϕ**

Definition: This defines whether or not the performance of the cushion depends on its position in space.

relevance: Cushions should perform their function in all appropriate sitting postures as well as in all wheelchairs incorporating an angle ϕ adjustment.

Characteristic: **Vulnerability**

Definition: This defines the level to which the pressure-distribution performance of a cushion is susceptible to mechanical breakdown.

Relevance: In daily situations a cushion is subjected to various sorts of mechanical load: transfers, the removal of the cushion so that the wheelchair can be folded, etc. An ideal cushion will be able to withstand these impacts, since its performance should be guaranteed beforehand and certainly when the sensibility of the wheelchair-cushion user is no longer present.

Characteristic: **Washability of the cover**

Definition: The possibility to remove, wash and restore the cushion's cover.

Relevance: A wheelchair-cushion is used intensively. For reasons of good moisture- and heat regulation that cushion should be selected of wich the cover is permeable to moisture. It is desirable for the cover to be cleaned at regular intervals.

Characteristic: **Wipability of cover**

Definition: The possibility to wipe clean a cover with soap and water, making the cover once again suitable for use.

Relevance: The intention here is to make a clear distinction between 'washability' and 'wipability'. If a cover is wipable it will not take up any moisture including transpiration. This is expressed as a negative score in respect of moisture regulation. Wipability can be considered as a small positive compensation for this.

Characteristic: **Odour resistance**

Definition: The level to which a cushion is able to eliminate the smell of urine and remain odour-free.

Relevance: Equipment, which is intended to absorb incontinence directly from the body, does not always work optimally. It is therefore important that the cushion or cushion cover can be cleaned in such a way that no smell of urine remains. In theory all cushions are faced with this problem.

Characteristic: **Moisture control**

Definition: The extent to which a cushion is able to take up and manage moisture as a result of a temporarily uncontrollable incontinence and the ease with which the cushion and its filling can be cleaned with ordinary tapwater.

Relevance: In principle, when incontinence is present, secretions by the body are absorbed with the aid of a catheter or a special incontinence pad. In some cases this is not always reliable. This means that the cushion regularly comes into contact with large amounts of moisture. This situation cannot always be solved immediately if the wheelchair-user is unable to rectify the situation himself. The cushion should be able to process the moisture in such a way that the discomfort and any possible damage to the user are minimised.
It is conceivable that the cover and the top layer of the cushion are completely permeable to moisture and that urine is absorbed by the next underlying layer. The cushion filling, after being wiped and rinsed, should be ready for use again immediately. Moisture control, given this definition, is a characteristic which is particularly relevant for a high-risk user (incontinence) type cushion. At the moment this definition is fairly wide-ranging. A discussion on the best way, in which incontinence fluid needs to be absorbed by the cushion, needs to be initiated.

Characteristic: **Durability of the cover**

Definition: The durability of the cover is the level to which the covering material and the structure of the cover is able to withstand for some time period a diversity of mechanical loads.

Relevance: The life expectancy of the cushion as well as its cover should be specified.

Characteristic: **Durability of the cushion**

Definition: This defines the extent of the changes in resistance to deformation as a result of the frequent loads being placed on the cushion during a certain time.

Relevance: A cushion not only has a 'technical' life expectancy but also a 'functional' one. If important characteristics deteriorate or no longer meet certain specifications, the cushion must be considered to be worn out, even though it may still look in good shape. Sometimes the opposite may be true.

Characteristic: **Age-resistance of cover**

Definition: The deterioration in quality of a cushion's cover as a result of wear and tear due to water, shampoo and sweat.

Relevance: A cover made from synthetic leather and fabric must have some resistance to sweat and cleaning agents; for fabrics this means that it is colourfast. For synthetic leather covers this means that the top layer does not come loose as a result of urea or water.

Characteristic: **Age-resistance of cushion**

Definition: The deterioration in the quality of cushion attributes as a result of heat and moisture.

Relevance: The technical and/or functional life-expectancy of a cushion may depend on physical influences; heat and moisture, for example, are important ageing factors.

Characteristic: **Fire resistance**

Definition: The extent to which a cushion is able to resist a small smoulder in the form of a cigarette burn.

Relevance: Dangerous situations resulting from a cigarette or cigar burns should be avoided, in order to prevent the outbreak of fire.

6.3 Analysis of testing results

This section discusses the results of the most important sitting characteristics. A short description of the testing method will be given and the assessment criteria, as set out by the wheelchair-cushion panel, will be presented. A preliminary analysis,, using the results of the different types of cushions in the survey, will attempt to give an indication of certain trends in relation to the materials and designs applied.

The method for the assessment criteria of pressure-distribution quality were determined and discussed in section 4.5. A different procedure was followed in establishing assessment criteria for other cushion characteristics. Per characteristic, one to eight cushions in the survey were selected with 'high', 'medium' and 'low' scores. In groups of two cushions, each with approxiamate scores, and in descending order, the importance of these specific characteristics in relation to specific user groups were assessed by each panel member. The score for each of the cushion types identified was translated into a 'target' level, an 'acceptable' level and an 'unacceptable' level. The resulting assessment criteria were discussed in a second meeting with panel members, using the assessment results of other cushions in the survey. This discussion did not lead to any changes of the assessment criteria. In addition the 'state-of-the-art' status of the cushions was also taken into account. It was agreed to confer a preliminary status on this set of assessment criteria and to evaluate this later in practical situations.

Section 6.5 presents an analysis of the overall results of the 'sitting' and 'transfer' characteristics of the cushions and therefore the possibility of achieving desirable combinations of characteristics in one single cushion. The influence of materials is summarised in section 6.5.1.

6.3.1 Stability

Stability is the capacity of a cushion to maintain the upper side of the pelvis in a roughly horizontal position when the upper half of the body leans sideways. Stability is considered to be the most important characteristic of the sitting support after pressure-distribution. A cushion with a minimum level of sitting stability is not only perceived as being uncomfortable, but it can also have negative effects on the sitting posture.

Stability is measured in the following way:
The test buttocks, with their test sensors removed, are placed on the cushion, which is subjected to a total load of 600 N. Weights of 2.5 kilos each are fitted to either side of the test buttocks. After one minute of symmetric load one of the weights is switched over to the other side, shifting the centre of mass outwards by 2.5 cm. The test buttocks will start to lean. The angle of inclination is measured immediately after the weights have been switched and then again one minute afterwards. The load is then applied symmetrically once again.
After a further minute the procedure is repeated; only this time the weights are switched to the other side of the test buttocks and the testing procedure is carried out once more.
The stability is calculated as the mean change of angle which occurs when the

weights are switched from left to right.

With the aid of the procedures described previously the wheelchair-cushion panel established the following preliminary assessment criteria, using the results for the cushions:

score	2	1	0
low-risk user cushion	$\leq 4°$	4-8°	> 8°
medium-risk user cushion	$\leq 4°$	4-6°	> 6°
high-risk user cushion	$\leq 3°$	3-4°	> 4°

According to the assessment system the target level received 2 points, the acceptable level 1, and the unacceptable level no points at all.

48 cushions were measured for their stability. The target level of 4° for the low- and medium-risk user cushions was attained by 30 cushions, whilst the 3° target level for high-risk user cushions was attained by 20 cushions.

All types of pressure-distribution systems and support structures are represented, with the exception of the air-filled cushions that consist of one compartment only.
These air-filled cushions have a stability of more than 10°; some air-filled cushions cannot be tested using this method, because the test buttocks simply topple over.
By splitting up an air-filled cushion into left and right-hand side compartments which are separated from each other, good results can be achieved, as can be seen in table 6-1. This is also the case for fluidised gel cushions.

Since unequal air pressure in the left and right hand sides of these cushions can lead to poor pressure-distribution, the 'sitting down' process should be carried out very carefully; the individual adopts a symmetrical posture while both compartments of air remain connected to each other. The sitting posture is maintained whilst the connection is closed.

number	pressure-distribution medium	mean	SD	minimum	maximum
18	foam	3.3°	1.1	1.8°	5.5°
3	air, divided surface	> 10°		1.9° *	> 10°
5	air, non-divided surface air/foam, idem ditto	> 10°		9.2°	> 10°
5	fluidised gel *	3.0°	1.8	0.9°	5.0°
4	non-fluidised gel	2.3°	0.5	1.6°	2.6°
2	fibres	2.8°		2.7°	3.2°
5	gel on foam	5.7°	3.6	2.8°	> 10°
4	visco-elastic foam + foam	4.2°	4.1	2.0°	> 10°
1	'filled' hammock	2.8°			

* result depends on whether left and right-hand compartments are divided.

Table 6-1 : Influence of pressure-distribution medium on stability.

The stability of foam cushions appears to deteriorate in proportion to the increase in thickness and decrease in firmness.
A foam cushion consisting of a 70 mm thick polyether and with a PDQ of 70, has a stability of 5.4° with a hammock as support structure. The Demo F cushion (100 mm DRAKA 9018 foam on a flat board) has a stability of 5.6°. This is well above the target level for the low risk cushion. Action should therefore be initiated to improve the stability of these cushions, without their relatively satisfactory level of PDQ being lost.

6.3.2 Surface softness

Surface softness is defined by the level to which a surface under load can prevent a pressure increase, due to a relatively small local deformation.
If this logic is followed a double layer of clothing should not lead to a local increase in pressure. In practice this means that the cover and the top layer of the cushion must deform instead of the buttocks.

Surface softness is tested by placing a button with a diameter of 10 mm and a thickness of 4 mm directly under one of the tuberosities between the test buttocks and the cushion. A pressure reading is then taken. The pressure in the tuberosity cells is recorded and compared with the normal value.
The pressure increase in relation to the previous test is then calculated and expressed in mmHg.

The panel decided on the following assessment criteria:

score	2	1	0
low-risk user cushion	≤ 75*	75-100	> 100
medium-risk user cushion	≤ 60	60-75	> 75
high-risk user cushion	≤ 50	50-60	> 60

* pressure increase in mmHg

Naturally, ideal situation exists when there is little or no pressure increase at all. For each of the different types of cushions the target levels can be said to be on the generous side. Many cushions on the market today, however, still do not manage to achieve target levels.

For a large part surface softness can be said to be dependent on the characteristics of the cover and the tension which develops when subjected to a load. For liquid- and air-filled cushions this tensile stress depends on the pressure which develops in the system. Table 6.2 presents the results in relation to the pressure-distribution medium and table 6.3 in relation to the type of cover used.

number	pressure distr. medium	mean	SD	minimum	maximum
18	foam	93.1	29.1	46	151
3	air, divided surface	62.3	1.1	61	63
5	air, non-divided surface air/foam, idem ditto	83.4	27.1	43	106
5	fluidised gel	63.2	35.5	35	122
4	non-fluidised gel	80.7	19.1	69	109
2	fibres	83.5		67	100
5	gel on foam	96.8	44.9	49	167
3	visco-elast. foam + foam	103.3	6.3	96	107
1	'filled' hammock	103.0			

Table 6-2 : Influence of pressure-distribution medium on the surface softness (mmHg).

The table would seem to suggest that a good result can be obtained by all types of pressure-distribution mediums. The surface softness is predominantly contingent on the type of cover used. Table 6-3 shows the results in relation to the different types of cover and pressure-distribution media. The cover appears to have a greater and more obvious influence on the definitive results than does the pressure-distribution medium.

number	cover	mean	SD	minimum	maximum
10	stretch cover	79.5	21.8	46	107
22	woven fabric	81.6	29.5	35	167
9	vinyl	97.2	22.7	60	131
2	coated woven fabric	129.5		110	149

Table 6-3 : Influence of the cover on the surface softness (mmHg).

6.3.3 Shock-absorption capacity

The shock-absorption capacity of a cushion is defined as its ability to absorb an extra load resulting from a vertical impact in the best possible way.

Shocks and vibrations, to which a wheelchair is subjected when used on an uneven surface, are perceived as uncomfortable. In principle shock absorption is a property of the wheelchair as a whole and should be defined as such. Shocks should be absorbed in the first place by a suspension system, fitted with shock absorbers without giving an unstable or erratic feeling. The position of the head should remain as stable as possible; otherwise extra fatigue may result, especially for persons with a clinical condition. This can in turn lead to a reduction in the functioning of neck muscles. Since most wheelchairs are not fitted with a suspension system, the shock-absorption capacity of the cushion is itself an important factor. It is not known to what extent, if any, these shocks may help or hinder the development of decubitus, given the fact that a pumping or massaging action may result.

The shock-absorption testing method is derived from methods carried out in the past by TNO (Weustink, 1988). The shock-absorption capacity is measured by placing a 600 N load on the cushion, using the test buttocks, and raising it by 15 mm and then dropping it onto the cushion.
The increase in pressure is registered in terms of time. The results of this exercise are shown in figure 6-1.

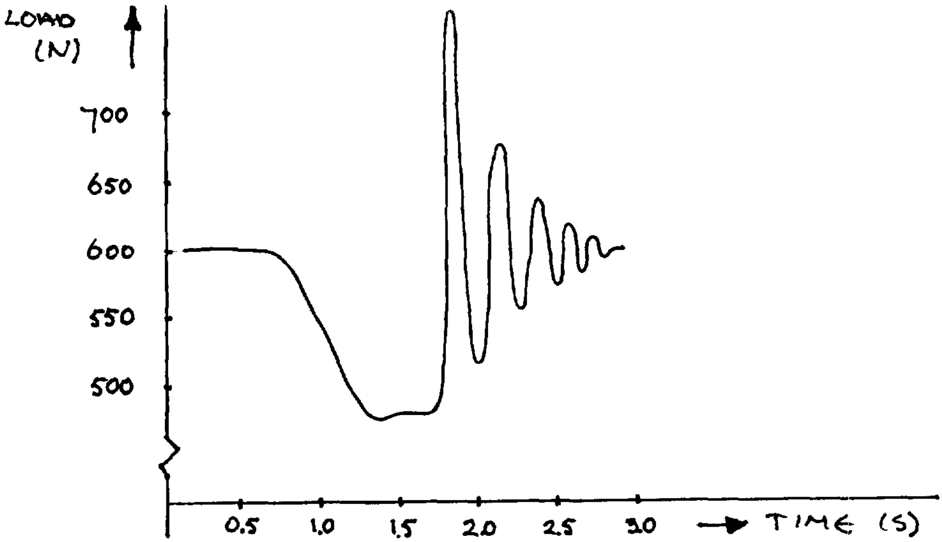


Figure 6-1 : Example of a load - time curve after dropping the test buttocks from a height of 15 mm.

The first and second peaks of the load are a measure of shock-absorption capacity.
The shock absorption capacity is defined by the height of the initial peak of load in N.
The preliminary assessment criteria, as established by the panel on the basis of the results for known cushions, are:

score	2	1	0
low-risk user cushion	≤ 360*	360-420	> 420
medium-risk user cushion	≤ 320	320-380	> 380
high-risk user cushion	≤ 280	280-340	> 340

* increase in load in N

The shock-absorption capacity appears to be defined primarily by the type of pressure-distribution medium used. Almost all cushions were tested on a flat board or hammock. Some foam cushions had a deformable springy structure. Table 6-4 demonstrates that liquid and gel cushions, and to a lesser extent air-filled cushions, do not satisfy the target level for the low risk cushion. Visco-elastic material in itself has insufficient shock absorption capacity: the lowest value in the table is that of a combination of foam with visco-elastic foam.
In general, foam is shown to have a reasonable shock absorption capacity. The values attained for foam cushions with a deformable, springy support structure lies below the average measured for foam cushions.

number	pressure-distr. medium	mean	SD	minimum	maximum
18	foam	360.2	84.9	262	555
3	air, divided surface	467.0	62.35	395	503
5	air, non-divided surface air/foam, idem ditto	493.0	70.16	443	616
5	fluidised gel	548.2	184.3	392	848
4	non-fluidised gel	568.7	114.1	461	697
2	fibre	310.0		284	336
5	gel on foam	499.0	150.8	337	725
4	visco-elast. foam, visco-elast. foam + foam	436.0	136.8	235	540
1	'filled' hammock	503.0			

Table 6-4 : Influence of pressure-distribution medium on the shock-absorption capacity (increase in load in N).

6.3.4 Moisture regulation

Moisture regulation is defined as the extent to which the cushion is capable of managing transpiration moisture.
Moisture situated in the contact plane between the seat and the buttocks softens the skin and can further decubitus. Moisture is perceived as being uncomfortable.

Moisture regulation is measured in the following way:
The cushion is turned upside down and placed in a bowl of water. The amount of water in the bowl is pre-defined. After 24 hours the amount of water left in the bowl is measured. The amount of water which has disappeared is calculated with the size of the cushion's surface and expressed in grams per m^2 per hour and is a measure of the cushion's moisture-regulating capacity. The method of testing was developed by TNO (Weustink, 1988).

On the basis of the test results for the known cushions the following assessment criteria was decided upon by the wheelchair-cushion panel. The values are expressed as moisture take-up in $gr/m^2/24h$.

score	2	1	0
low-risk user cushion	≥100*	100-50	< 50
medium-risk user cushion - normal	≥125	125-75	< 75
medium-risk user cushion - transpiration	≥175	175-100	<100
high-risk user cushion - transpiration	≥175	175-100	<100
high-risk user cushion - incontinence	≥175	175-100	<100

* moisture take-up in $gr/m^2/24h$.

In theory the high-risk user cushion for incontinence has been developed with a system for moisture control in mind. This system should therefore have an optimum level of moisture regulation, even if in practice there is as yet no necessity for moisture control.

The wheelchair-cushion panel made clear-cut choices in respect of moisture-regulation characteristics for all the user groups and also for the users of the low-risk user cushion. As this is not strictly according to what generally happens in practice the assessment criteria for the low-risk user cushion were, in consultation with the wheelchair-cushion panel, not placed too high.

Of the 48 cushions tested only 12 can be said to have some moisture-regulation. Only 6 of these satisfy the minimum requirements of 50 $gr/m^2/24h$.

From table 6-5 it emerges that all 'open' materials have sufficient capacity to meet the requirements. Section 1.4.2 presented the results of a practical test on a test subject, the aim of which was to validate the test methodology used for moisture regulation.

The Demo F cushion and the Postura cushion, with moisture regulation of 154 and 182 $gr/m^2/24h$ respectively, produced a relative humidity in the test subject of 95% after 2 hours. The Demo D cushion, however, had a moisture regulation of 232 $gr/m^2/24h$ after 2 hours with 80% relative humidity, even falling afterwards. As discussed already in section 1.4.2. this probably has something to do with the heat regulation. Moisture discharge as such is always accompanied heat discharge. The more heat is discharged, the lower the temperature on the surface of the buttocks, thus reducing the production of sweat.

cover	pressure distr. medium	support structure	moisture regulation [gr/m²/24h]
nylon velours	polyether	hammock	161
coated woven fabric	perfo-foam rubber	flat board	98
corduroy	latex foam with holes *Postura cushion*	webbing	182
coated woven fabric	pu foam	shell	45
Gore-tex	flocculent polyether	hammock	175
coated woven fabric	pu foam	flat board	27
cotton	silicone foam	hammock	103
open weave	air, divided surface	flat board	67
woven fabric	air, non-divided surf. with 12 mm pu foam top layer	shell	78
cotton	fibre	hammock	180
stretch cotton	gel on foam	flat board	47
coated woven fabric	foam-gel-foam	flat board	43
Gore-tex	visco-elastic foam	flat board	179
cotton	foam + visco-elast. foam	flat board	149
stretch	100 mm DRAKA 9018 foam *Demo F cushion*	flat board	154
woven fabric	vulcanised hair *Demo D cushion*	trampoline	232

Table 6-5 : Influence of cover and pressure-distribution medium on the moisture regulation.

Though the experiments on the test subject do not provide a definitive verdict on the validity of the test methods, the conclusion can be made that the method used gives a comparative way in which to analyse the moisture-regulation capacity of a cushion. Better methods of testing are unfortunately not available as yet. It seems a very difficult task to develop a test method which corresponds more or less with what happens in the micro-climate between the skin and the cushion and which can therefore establish the precise relationship between body temperature and the production of sweat.

Sometimes pvc-vinyl cushion covers are given a sheepskin cover for the purposes of moisture regulation. Section 5.6 discussed the influence of synthetic sheepskin on the pressure-distribution. Tests were also carried out on the fleece in order to establish its moisture regulation capacity.
Two tests were performed: one on a cushion with a fabric cover, the other using a cushion with a pvc-vinyl cover.
The cushion with the fabric cover had a 80 mm thick polyether pressure-

distribution medium and was measured on a hammock support structure. The following picture developed:
The cushion with a fabric cover, when fitted with the fleece, does not take up any more moisture than when fitted without the sheepskin, but does allow more moisture through. The moisture regulation is improved by 5.6% to 170.1 gr/m^2/24h, thereby almost attaining the target level for a high-risk user cushion of >175 gr/m^2/24h.
It would appear that the sheepskin fleece does not take up any moisture, but lets it pass through.

	Water take-up	Water passed through	total
Foam + fabric cover without sheepskin	25.0 gr	136.0 gr	161.0 gr/m2/24h
Foam + fabric cover with sheepskin	23.9 gr	146.2 gr	170.1 gr/m2/24h
Foam + vinyl cover with sheepskin	1.9 gr	68.8 gr	70.7 gr/m2/24h

Table 6-6 : Moisture-regulation of a synthetic sheepskin fleece placed on two different cushions.

The cushion with the pvc-vinyl cover has a pressure-distribution medium of 60 mm foam rubber and webbing as a support structure. It had a moisture regulation of 70.7 gr/m^2/24h. The fleece absorbs almost no moisture whatsoever, the water vapour evaporating via the sides. The value remained below the target level for the low-risk user cushion (>100 gr/m^2/24h).

Literature sources (Denne 1979) seem to suggest that a synthetic fleece on a layer of wool does absorb moisture. The eventual effect on the relative humidity in the contact plane remained untested.

6.3.5 Heat regulation

Heat regulation is defined as being the extent to which a cushion is able to regulate the temperature in the contact plane between the seat and the buttocks. A rise in temperature in this plane produces a sticky feeling which is perceived as being uncomfortable. A temperature increase leads to more transpiration.

For individuals, forced to adopt a sitting position for long periods, a rise in temperature is undesirable on account of the increase in cell metabolism.

Restricted supplies of oxygen and nutrients will in any event lead to damage.

The heat regulation is expressed in terms of Watts, as heat flow passing through the cushion after 6 hours per m^2.
The test method was developed by TNO and is derived from BS 5335 (1976): An aluminium plate is placed on an electric blanket (thermostat 36°). This ensures an even supply of heat. Temperature and heat flow metres are applied to the aluminium plate. The seat is then placed upside down on top of the blanket. Temperature metres are likewise placed on top of the now inverted seat. On top of this a piece of grating is placed, on which loads of up to 60 kilos can be placed. Once the electric blanket has been turned on, the heat flow and temperatures are measured at intervals during a period of 6 hours.

The wheelchair panel established the following set of assessment criteria on the basis of the cushions used in the survey.

score	2	1	0
low risk cushion	≥ 16*	16-10	< 10
medium risk cushion	≥ 18	18-12	< 12
high risk cushion	≥ 18	18-14	< 14

* heat flow in W/m^2 after 6 hours

The higher the rate of heat flow, the more heat is discharged and therefore the less warm the cushion will feel.

Additional experiments taken on one test subject (Engelbert 1992) have shown that heat flows measured for cushions are very similar to those observed in test subject experiments. With one important difference however: in practice evaporation of moisture will extract evaporation energy from the skin, thus producing extra heat flow. If the moisture is not discharged quickly enough, fluid moisture will develop on the skin, restricting any additional heat flow. This explains the fact that in the test subject experiment the Demo D cushion had the lowest temperature, since heat is discharged as a result of the low relative humidity due to disappearing water vapour. This phenomenon is not incorporated into the results of the laboratory experiments.

Table 6-7 shows that in general the foam cushions do not meet target levels. The test subject perceived the foam cushions as being on the warm side.

number	pressure-distribution medium	mean	SD	minimum	maximum
18	foam	12.2	2.67	7	19
2	air, divided surface	34.0	0.00	34	34
5	air, non-divided surface air/foam, idem ditto	30.6	22.41	11	61
5	fluidised gel	26.0	18.84	10	57
4	non-fluidised gel	37.0	7.61	27	45
2	fibre	11.0		10	12
5	gel on foam	30.4	27.28	12	78
4	visco-elast. foam + foam	13.3	2.36	10	15
1	'filled' hammock	25.0			

Table 6-7 : Heat regulation in relation to the pressure-distribution medium (W/m^2).

The silicone foam which has an open foam structure does, however, produce a satisfactory result: 19 W/m^2. The gel cushions have a high heat capacity. A few hours elapsed before the cushion heats up.
For the test subject experiment the gel cushion took 3 hours to reach the the same temperature, which a cushion with a latex filling attained after just one hour.
The air-filled cushions score highly when 'holes' exist in the construction.
A cushion, consisting of foam, fluidised gel and foam, attains a satisfactory level of heat regulation of 25 W/m^2 with a negligible moisture-regulation rating of 43 $gr/m^2/24h$ (see table 6-5). This represents a worthy compromise but is still insufficient.

A fleece has an insulating effect on heat regulation with hardly any heat being discharged. In both of the before mentioned experiments the heat flow decreased by 32% to 7.8 W/m^2 for a cushion with a fabric cover and falls likewise by 32% to 8.5 W/m^2 for a cushion fitted with a pvc-vinyl cover, measured after 3 hours.
This is far below the target level for a low risk cushion (>16 W/m^2)

The general conclusion which can be made from the tests on the synthetic fleece might be that the fleece used makes a clear improvement to the pressure-distribution quality and to the moisture regulation, but performs badly in heat regulation.

	without sheepskin	with sheepskin	difference
Foam + fabric cover on hammock	11.5 W/m2	7.8 W/m2	-32 %
Foam + vinyl cover on webbing	12.5 W/m2	8.5 W/m2	-32 %

Table 6-8 : Heat-regulation of a synthetic sheepskin fleece on two different cushions.

6.3.6 Consistency of shape

Consistency of shape is defined as the horizontal shift in the upper side of the loaded cushion in relation to its underside as a result of shear forces which develop from a poor sitting posture.

A poor sitting posture produces a shear force in the sitting plane. A friction force develops in the seat as a reaction force to this shear force. When the friction force is realised, the upper side of the cushion shifts horizontally in relation to the underside of the cushion. This shift is unwelcome since the tuberosities slide forwards and the pelvis tilts backwards. This places more load on the coccyx and leads to the lumbar spinal column adopting a kyphosis.

The consistency of shape is measured by loading the cushion with test buttocks of 600 N. These test buttocks have the same size, shape and structure as the test buttocks, used for the testing of the pressure-distribution, without test sensors being applied. These test buttocks are fitted with a denim fabric. A horizontal traction force of 150 N is applied to the test buttocks. The horizontal shift of the test buttocks under the influence of this traction force is expressed in mm.

On the basis of the existing cushions the wheelchair-cushion panel established the following assessment criteria:

score	2	1	0
low-risk user cushion	≤ 13*	13-18	> 18
medium-risk user cushion	≤ 13	13-18	> 18
high-risk user cushion	≤ 12	12-16	> 16

* horizontal shift in mm

The influence of the pressure-distribution medium on the consistency of shape is shown in table 6-9. Gel's consistency of shape, as was to be expected, was low, with non-fluidised gel faring worse than fluidised gel. This is probably due to the thickness of the gel layer which develops under load. This is partly dependent on the shape of the support structure. For most fluidised gel cushions the gel thickness is low. Air-filled cushions with a divided surface also score badly. This result is likewise due to the height of the cells which remain under load.

number	pressure-distribution medium	mean	SD	minimum	maximum
18	foam	13.4	2.06	10	19
3	air, divided surface	20.6	4.04	16	23
5	air, non-divided surface air/foam, idem ditto	16.4	2.07	15	20
5	fluidised gel	17.0	2.23	14	20
4	non-fluidised gel	30.0	6.30	21	35
2	fibre	15.0		14	16
5	gel on foam	14.6	5.0	10	24
4	visco-elast. foam + foam	14.0	1.73	12	15
1	'filled' hammock	13.0			

Table 6-9 : Influence of the pressure-distribution medium on the consistency of shape (horizontal shift in mm).

6.4 Order of importance

In order to evaluate the overall quality of a cushion in relation to a user group, the importance of these qualities in respect of each other, the so-called weighted factors, must be identified, plus the assessment criteria to which a cushion must satisfy a particular user group.
The wheelchair-user panel was asked to qualify the weighted factors.

In order to establish these weighted factors, the characteristics were categorised into 4 groups:

- sitting characteristics
- sitting down/transfer characteristics
- cleaning characteristics
- durability

Each of the panel members was asked to indicate per two groups of characteristics how much more important one group is than the other in relation to a cushion type for a specific user group.

Systematic processing of data enabled to calculate the combined importance of groups of characteristics for a specific user group.
Then the list of sitting characteristics was given to the panel to indicate the order of importance per type of cushion.
This provided an 'average' order of importance per type of cushion. In a collective session the panel decided how much more important one characteristic was than the next. The last question asked was how much more important the penultimate characteristic was than the very last characteristic. On the basis of this information the weighted factors could be calculated and expressed as a percentage of their share in the assessment.
The same was done for the transfer characteristics.
The method used was developed by the TNO's Medisch Fysisch Instituut (1976).

The cleaning and durability characteristics were not included in this procedure. The percentage of these categories were divided equally over the characteristics. The overall results were presented to the panel in written form for their comments, but this did not lead to any modifications. The results are shown in table 6-10.

Characteristic:	low risk	medium risk	med. risk transpiration	high risk transpiration	high risk incontinence
Sitting characteristics	**30.0%**	**36.0%**	**32.0%**	**35.0%**	**35.0%**
Pressure distr. quality	10.8%	14.2%	13.1%	15.8%	15.8%
Surface softness	5.4%	5.9%	5.3%	6.1%	6.1%
Stability	10.2%	11.4%	10.6%	9.6%	9.6%
Shock absorption capacity	3.6%	4.5%	3.0%	3.5%	3.5%
Moisture and heat regulation	**7.0%**	**9.0%**	**12.0%**	**16.0%**	**16.0%**
Moisture regulation	3.5%	4.7%	7.1%	9.8%	9.8%
Heat regulation	3.5%	4.3%	4.9%	6.2%	6.2%
Sitting down/transfer	**34.0%**	**30.0%**	**30.0%**	**26.0%**	**26.0%**
Sacral indentation	4.0%	3.6%	3.6%	3.1%	3.1%
Frontal indentation	4.8%	4.2%	4.2%	3.65%	3.65%
Lateral indentation	4.8%	4.2%	4.2%	3.65%	3.65%
Longitudinal smoothness	5.1%	4.5%	4.5%	3.9%	3.9%
Transversal smoothness	5.1%	4.5%	4.5%	3.9%	3.9%
Creasing	5.1%	4.5%	4.5%	3.9%	3.9%
Consistency of shape	5.1%	4.5%	4.5%	3.9%	3.9%
Cleaning	**16.0%**	**15.0%**	**17.0%**	**15.0%**	**16.0%**
Washability of cover or	8.0%	7.5%	8.5%	7.5%	5.3%
Wipability of cushion			-	-	5.3%
Odour resistance	8.0%	7.5%	8.5%	7.5%	5.3%
Moisture control	-	-	-	-	5.3%
Durability	**13.0%**	**10.0%**	**9.0%**	**8.0%**	**7.0%**
Durability of cover	3.25%	2.5%	2.25%	2.0%	1.75%
Durability of cushion	3.25%	2.5%	2.25%	2.0%	1.75%
Age resistance of cover	3.25%	2.5%	2.25%	2.0%	1.75%
Age resistance of cushion	3.25%	2.5%	2.25%	2.0%	1.75%
Others:					
Reliability	-	-	-	-	-
Fill-ratio sensitivity	-	-	-	-	-
Positioning sensitivity	-	-	-	-	-
Vulnerability	-	-	-	-	-
Influence of angle ϕ	-	-	-	-	-
	100	100	100	100	100

Table 6-10 : Weighted factors per characteristic per type of cushion.

The 'reliability' group was included 'for the record'.
This is because characteristics in this group are of a different nature when set against the other characteristics. They relate primarily to the advantages and disadvantages of the different systems applied in relation to the level of reliability which these systems have.

In presenting the results of this preliminary cushion survey, a decision was taken to calculate a 'suitability valuation' on the basis of sitting characteristics (e.g. moisture and heat regulation) and transfer characteristics.
This suitability valuation is expressed as the maximum attainable score from both these main groups.

6.5 Analysis of combinations of characteristics

With the aid of the assessment criteria and the weighted factors discussed in section 6.3 and 6.4, a score can be calculated which will indicate the suitability of a cushion for a particular user group. The score also provides an indication as to what extent these different characteristics can be combined with each other.

Some characteristics for a particular type of cushion are so specific that a lower limit has to be established in order to allocate a cushion to this type. These criteria are called threshold requirements. An introduction to these threshold requirements was given in section 4.5.
In principle the 'non-acceptable' or 'no-score' levels for all characteristics must be taken into account. Characteristics which have received a high weighted factor, and which therefore contribute proportionally more to the overall score, come in for special consideration, since they are evidently 'type-defining' characteristics.

In this cushion survey - the first in a planned series of product evaluations - three characteristics were provisionally selected for which effective threshold requirements were specified.

-the pressure-distribution,
for all types of cushions;
-the moisture regulation,
for the medium-risk user cushion (transpiration) and the high-risk user cushion (transpiration);
-moisture control,
for the high-risk user cushion (incontinence).

For all types of cushions the 'no-score' limit was used for pressure-distribution quality, except for the low-risk user cushion and the high-risk user cushion (incontinence). Respective limits for these were PDQ$\geq$30 and PDQ$\geq$55, in the first instance in order not to exclude any of the cushions from the survey and in the second instance in order to attain a somewhat larger group.
Cushions designed for excessive transpiration need to have a moisture

regulation which at least meets the 'no-score' level. Since only a few cushions currently meet this specification, it was decided to lower the threshold requirement.This ensures that in clinical situations more choices are available. The threshold requirement for 'moisture control' only has a bearing on the high-risk user cushion (incontinence). The limit for this characteristic is the cushion's suitability for rinsing under a watertap and **not** measured on the basis of the cushion's ability to absorb a certain level of moisture under *controllable* conditions, as the intention is of this characteristic. No cushions currently available meet this specification.
The following table lists the threshold requirements used in the survey:

	Threshold requirement			**No-score level**	
	PDQ	moisture regulation [gr/m²/24h]	moisture control	PDQ	moisture regulation
low-risk cushion	≥ 30	-	-	< 45	< 50
medium-risk cushion	≥ 55	-	-	< 55	< 75
medium-risk cushion (transpiration)	≥ 55	≥ 25	-	< 55	< 75
high-risk cushion (transpiration)	≥ 65	≥ 50	-	< 65	< 100
high-risk cushion (incontinence)	≥ 55	-	+	< 65	< 100

Table 6-11 : Threshold requirements and no-score levels in relation to cushion types.

When these threshold requirements are applied to cushions in the survey, only 13 of the 47 cushions satisfy the threshold requirement for the medium-risk user cushion (transpiration).
Table 6-12 lists the results for cushions which satisfy the threshold requirements for the different types of cushions. The number of cushions is indicated which meet the threshold requirements and the mean and the SD of the scores, expressed as a percentage of the maximum score, the sitting characteristics, the transfer characteristics and the combination of these two characteristics. The maximum score recorded in the survey is also included.

The table shows that the average scores and the maximum readings are lower in proportion to the increased risk of the user group. This means: the greater the requirements, the more difficult the characteristics can be combined with each other. The maximum score for the sum of sitting characteristics and transfer characteristics decreases from 77% to 53% of the maximum possible score.

	number		sitting attributes	transfer attributes	score total
low-risk cushion	47	average:	55.5%	54.2%	54.8%
		SD	16.7%	20.7%	10.0%
		max.	95%	93%	77%
medium-risk cushion	26	average:	55.3%	51.4%	52.8%
		SD:	12.6%	18.5%	9.8%
		max:	84%	78%	68%
medium-risk cushion (transpiration)	13	average:	56.6%	43.9%	51.5%
		SD:	16.2%	19.5%	9.6%
		max:	83%	78%	65%
high-risk cushion (transpiration)	5	average:	48.2%	36.6%	44.4%
		SD:	18.1%	4.0%	12.7%
		max:	72%	41%	62%
high-risk cushion (incontinence)	10	average:	32.7%	47.4%	37.6%
		SD:	16.6%	11.4%	10.0%
		max:	62%	63%	53%

Table 6-12 : Suitability valuations for sitting characteristics, transfer characteristics and a combination of these, in relation to the type of cushion (as percentage of maximum score).

If the no-score level for the 6 sitting characteristics is used as the threshold requirement, only 5 cushions can be categorised as low-risk cushions, 1 as medium risk, 1 as medium risk (transpiration) and no cushions whatsoever as high risk.

Table 6-13 and 6-14 give the results for low- and medium-risk user cushions in relation to the pressure-distribution medium used. The different cushion systems which are used appear to produce a poor score for one or more characteristics.
The design of a cushion needs to maximise the advantages of an applied system and needs to eliminate or offsett the disadvantages.

number	pressure distr. medium		sitting attributes	transfer attributes	total score
18	foam	average:	57.2%	59.9%	58.7%
		SD:	17.2	20.5	6.0
3	air,	average:	67.2%	24.5%	46.7%
	divided surface	SD:	15.8	3.4	7.6
5	air, non-divided surface	average:	42.1%	46.5%	44.2%
	air/foam, idem ditto	SD:	11.3	13.9	7.1
5	fluidised gel	average:	63.4%	54.5%	59.2%
		SD:	17.2	12.0	9.5
4	non-fluidised gel	average:	46.2%	68.1%	56.6%
		SD:	6.8	9.4	7.9
2	fibre	average:	72.3%	18.7%	46.6%
		SD:	32.5	5.3	19.4
5	gel on foam	average:	51.8%	58.5%	55.1%
		SD:	9.4	16.1	5.6
4	visco-elast. foam +	average:	56.2%	61.5%	58.8%
	foam	SD:	18.5	29.9	19.5
1	'filled' hammock		37.0%	43.4%	40.1%

Table 6-13 : Suitability valuations for low-risk user cushions in relation to pressure-distribution medium (as percentage of maximum score).

number	pressure distr. medium		sitting attributes	transfer attributes	total score
7	foam	average:	57.9%	58.5%	58.1%
		SD:	8.2	19.7	5.1
3	air,	average:	56.1%	32.8%	46.8%
	divided surface	SD:	14.6	7.5	7.7
5	air, non-divided	average:	36.0%	51.7%	44.3%
	surface	SD:	14.2	14.7	9.6
	air/foam, idem ditto				
4	fluidised gel	average:	59.2%	61.0%	59.9%
		SD:	8.0	9.5	5.2
0	non-fluidised gel	average:	-	-	-
		SD:	-	-	-
1	fibre	average:	83.9%	28.5%	61.7%
		SD:			
2	gel on foam	average:	47.7%	59.3%	52.4%
		SD:	9.1	6.0	7.8
2	visco-elast. foam +	average:	57.1%	49.0%	53.8%
	foam	SD:	7.2	29.7	16.2
1	'filled' hammock		-	-	-

Table 6-14 : Suitability scores for medium-risk user cushions in relation to the pressure-distribution medium (as percentage of maximum score).

6.5.1 Review of the influence of materials and constructions on cushion characteristics

In the discussion, held in section 6.4 on the results of individual characteristics as well as in analyses of pressure-distribution and moisture- and heat-regulation, conclusions can be made as to the positive as well as negative effects of the different materials and designs used on the characteristics listed. By analysing the results it emerges that some materials have a high performance range for certain characteristics. Extremely good results as well as extremely poor ones can be attained by foam, when used as a pressure-distribution medium. The result itself depends on the quality of the foam used, its thickness and the type of support structure used. The conclusion cannot be made that foam, as such, has a positive or negative influence on the definitive result. This is also true of many materials in relation to certain characteristics.

Table 6-15 presents the contributions - in positive as well as negative terms - of different materials and support structures to the characteristics. The gaps in the table mean that good results can be obtained as long as the correct principles are applied. For combinations which have a ± score the effects are doubtful or critical. In these cases extra consideration must be paid to achieving better results

The table shows that almost all materials have negative aspects associated with them. The stretch cover and the vulcanised hair pressure-distribution medium provide exceptions to this. The conclusion is that at the design stage one should always try to eliminate the negative aspects of materials and constructions by compensating for these with other materials.
It is noticeable that a good pressure-distribution can be achieved using almost all materials with the exception of non-fluidised gel.

Worth special consideration is 'reliability'. The characteristics which determine reliability reflect the fact that the pressure-distribution performance of the cushion is assured at any given moment and under any given circumstance. The ideal situation, of course, is when this is indeed the case.
The level of reliability is virtually inherent in the systems applied.

The following characteristics have already been identified and described in section 6.2.1:
- the fill-ratio sensitivity
- the positioning sensitivity
- the vulnerability
- the influence of angle ϕ

In this survey the *fill-ratio sensitivity* relates to air- and liquid-filled cushions. Refillable air- and water-filled cushions have been designated as 'fill-ratio sensitive'.

The positioning sensitivity of a cushion system in practice is not that critical. In fitting the cushion to the user, a cushion will almost certainly be subject to a careful positioning procedure. The aim is for the user to adopt the same position in the wheelchair and on the cushion. In this respect it is important that the cushion is positioned accurately and individually in the wheelchair in relation to the backrest, so that an optimum sitting posture can be realised as well as optimum cushion performance.
The positioning sensitivity of a cushion is measured by taking a second PDQ reading, this time with the tests buttocks positioned 2.5 cm forwards. Air- and liquid-filled cushions which, when subjected to a load, only have a thin layer between the buttocks and the support structure, are sensitive to 'bottoming out'.
By *vulnerability* is meant the extent to which the pressure-distribution performance of a cushion is susceptible to mechanical damage. In day to day use a cushion is subject to a number of different sorts of mechanical forces: transfers, removal of the cushion from the wheelchair etc. An ideal cushion should be able to cope with such forces, since its performance should be guaranteed. For individuals who have lost sensibility this is essential.
Cushions containing a pressure-distribution medium, which is held in place by a sealing, appear to fall apart quite frequently. For this reason these cushions in this survey are assumed to be 'vulnerable' to at least some extent.

When the performance of the cushion is dependent on its position in space, the options for that cushion are limited. It should be possible to use cushions for a wide range of sitting postures and therefore they should be suitable for wheelchairs with an adjustable ϕ angle.

The pressure-distribution performance of cushions, with a pressure-distribution medium consisting of fluidised gel, or viscous or watery liquid, is assumed to be dependent on angle ϕ to some degree, since the fluid has a tendency to flow towards the lowest gravitational level. For protracted periods of sitting an adjustment possibility is required, that is, to chance angle ϕ. The performance of a cushion should not be dependent on this.

The conclusion of this analysis might be that air- and liquid-filled cushions are less suitable for use with a wheelchair, since they are vulnerable and an optimum performance is 'fill-ratio sensitive'.

	pressure-distribution	stability	surface softness	shock-absorb. capacity	moisture-regulation	heat-regulation	consist. of shape
Cover:							
vinyl	-	n/a	-	n/a	-	n/a	n/a
woven fabric	±	n/a	±	n/a	+	n/a	n/a
stretch	+	n/a	+	n/a	+	n/a	n/a
Pressure distr. medium							
foam		±		+		-	+
perforated foam		±		+		±	+
foam, cut-out		±	+	+		-	+
non-fluidised gel	-			-	-	+	-
fluidised gel divided le-ri		+		-	-	+	
air (1 cell only)		-		-	-		-
air (> 1 cell)		-		-		+	-
air (> 1 cell, divided le-ri		+		-		+	-
vulcanised hair					+	+	+
fibre					+	±	
visco-elastic foam		+		-			+
Support structure							
flat board	-		n/a	-	-	-	
trampoline	+	+	n/a	-	+	+	
hammock	+	+	n/a	-	-	-	
webbing	+	+	n/a	+	+	+	
contoured shell	+	+	n/a	-	-	-	+

n/a = not applicable

Table 6-15 : Contribution of materials and constructions to cushion characteristics.

6.6 Summary and conclusions

The quality of a seating support in wheelchairs is not determined by pressure-distribution alone. A number of other characteristics exist which influence the perception of comfort, and which go towards minimising decubitus risk or which create the preconditions for adopting a satisfactory sitting posture.
The characteristics of a cushion can be divided into 'sitting characteristics' and 'transfer characteristics'. Other characteristics associated with 'cleaning', 'reliability' and 'durability' must also be considered.
In addition to pressure-distribution, typical sitting characteristics include sitting stability, surface softness, shock absorption capacity and moisture and heat regulation.
Important transfer characteristics include smoothness, indentation, consistency of shape and creasing.

In order to determine a cushion's quality it is not only the assessment criteria of individual characteristics for specific user groups, but also the collective contributions in the definitive evaluation.
The significance of each of the characteristics in relation to each other, the so-called weighted factors, are expressed as a percentage which the characteristic in question has in the overall evaluation.
A wheelchair-cushion panel determined these assessment criteria. The 9 member panel used 17 selected cushions, both familiar and unfamiliar, the test results for which were unknown. They were presented with a large number of choices which were processed in systematic fashion into assessment criteria and weighted factors. The results and the consequences of these, based on the results for the survey cushions, were then discussed at a second meeting and refined into a definitive set of assessment criteria.
The result was that for each of the five user groups defined a specific mix of desirable characteristics was established and the collective significance of characteristics in the overall quality was indicated.

The test results for the different kinds of sitting characteristics presented and discussed in relation to the materials and constructions used, show that some of these materials and constructions have specific advantages (as well as disadvantages) in relation to a specific user group.

The results taken for combinations of characteristics for the different user groups, that is, the results defining cushion quality, show that substantial improvements can be made.

The use of synthetic sheepskin, of sufficient thickness and suppleness, on a cushion with a pvc-vinyl cover generally improves the pressure-distribution quality and the moisture-regulation but not to the level set for a low-risk cushion. On the other hand this leads to a deterioration in the heat-regulation.

For the design of good cushions manufacturers must maximise use of the specific advantages of materials and constructions and eliminate the disadvantages as much as is possible. The assessment criteria developed for the 5 different user groups can serve as a standard in evaluating cushions.
Special consideration needs to be given to the reliability aspects associated with the various pressure-distribution systems.

7.0 Development of experimental cushions

Throughout the cushion survey, from its concept to the concluding product evaluation, a constant series of experiments was carried out in order to gain a better insight into the subject matter. Chapter 3 analysed the way in which the pressure-distribution of cushions works by performing simple experiments, using various thicknesses of foam, a trampoline as support structure and the influence of the cover on the pressure-distribution. Further experiments were carried out into the effects of synthetic sheepskin on the pressure-distribution and on moisture- and heat-regulation.
Section 7.1 of this chapter presents the results of a number of these experiments. These tests examine the different support structures, the different pressure-distribution media and the different compositions of pressure-distribution materials. These experiments formed the basis to the development of five so-called demo cushions. These cushions were designed and developed with the express intention of examining specific combinations of characteristics. The demo cushions were included in the product evaluation and, as such, were analysed with respect to the same characteristics as for the commercially available cushions. Section 7.2 describes the objectives and results for the demo cushions.

7.1 Description of experiments

The experiments at the beginning of the project were carried out simultaneously with the development of the test buttocks.
These focused on three lines of questioning:

- What is the influence of the support structure? How can the support structure be optimised?
- Is it possible to produce and manipulate foam in such a way that a better pressure-distribution can be obtained?
- Can vulcanised natural fibres, such as coconut fibre and goat's hair - referred to hereafter as 'cocohair' - which supposedly have good moisture and heat regulating properties - also be used to attain good pressure-distribution?

A presentation will now follow of a number of experiments which will helping answer these questions. It should be said that, through lack of time and funding, it was not possible to attempt a *systematic* optimisation of the various variables involved. This however was not the primary aim of this supplementary survey.

The pressure-distribution is dependent on a wide range of variables. In order to gain an understanding of their individual effects, each variable needs to be changed in isolation to the rest which are held constant.

Experiments were carried out with two types of support structure:
- the 'trampoline'
- the deformable support structure

and three types of different pressure-distribution media:
- foam manipulated by means of foam wedges of varying quality,
- foam manipulated by means of foam rings of varying quality,
- non-homogeneous vulcanised natural fibres of varying quality and composition.

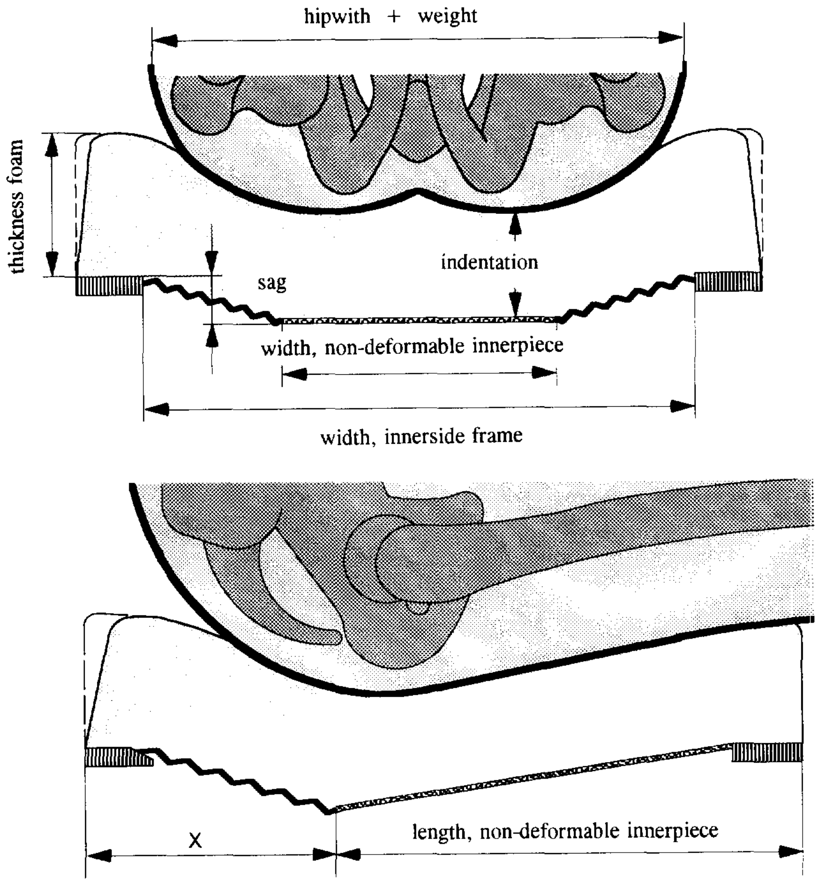


Figure 7-1 : Variables in the design of a deformable support structure in cross section and longitudinal section.

Variables, which influence the shape of the support structure when placed under load, are visualised in figure 7-1. The more conformity the shape of the support structure has with that of the buttocks, the less the relative deformation of the pressure-distribution medium needs to be and the less 'critical' the characteristics of this medium will be, in this case foam and cocohair. This issue was already discussed in chapter 3.0

In figure 7-2 the dimensions of the support structures used in the experiments are illustrated.

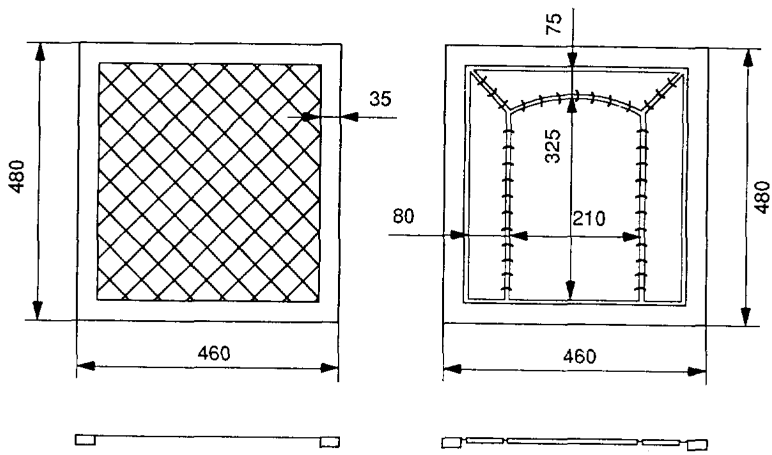
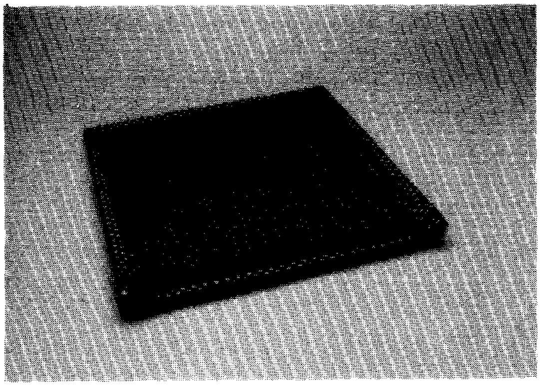
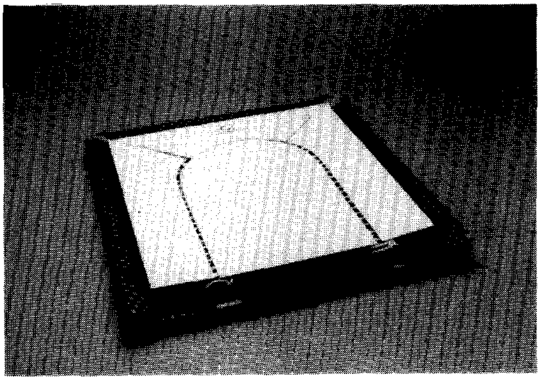


Figure 7-2 : Dimensions of support structures used in the experiments (in mm).

The dimensions of the cushions and the frames are based on the dimensions of the test buttocks and the operational area of the pressure-distribution on the cushion. The exact location where the tuberosities should be positioned is predetermined in the design. At the back of the cushion, in particular, there must be an element of 'overhang', in view of the frame construction of the cushion. The length of the cushion, based on an average thigh length of 515 mm and an average 'relationship' between the bodily dimensions and the product dimensions of 75 mm (Staarink 1995), is:
515 - 75 = 440 + 40 (rearside overhang) = 480 mm
The width is based on the hip width of the test buttocks (340 mm) plus an open space, partly as a result of the frame construction of 60 mm. Two photographs (photograph 7) show both these support structures.



'trampoline'

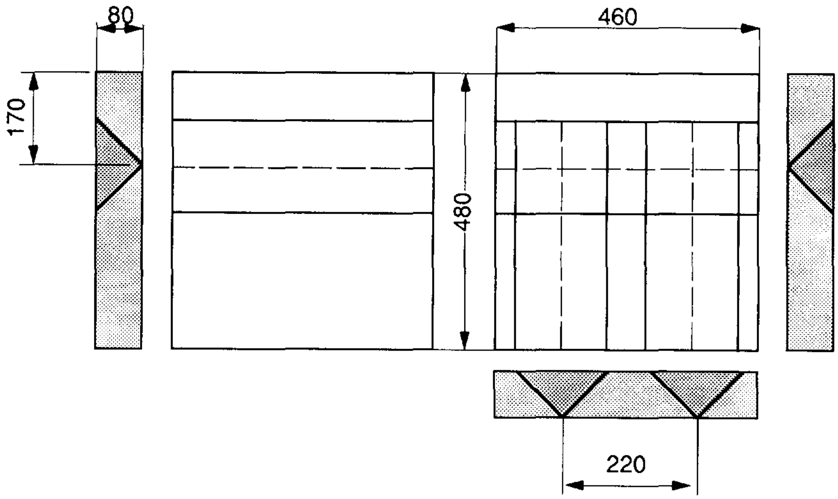


deformable support structure: model no. I

Photograph 7: Support structures used in the experiments.

The foams used were modified in two different ways. These modifications were aimed at minimising the reaction forces at the place where the greatest deformations are to be expected. This means that the density (i.e the reaction force under load) needs to be as low as possible at a point under the tuberosities running outwards.

Experiments were carried out using a so-called 'wedge' construction and a 'pattern' construction. These constructions can be explained as follows:
The wedge construction is derived from the supposition that the tuberosities might be relieved by placing a piece of foam under them with a lower density in a simple, easy-to-produce shape, which roughly resembles the shape of the buttocks when placed under a load.
The wedge construction in version 1 was so successful that a second construction was made. Figure 7-3 shows the dimensions of these two constructions.



version 1
tuberosity wedge

version 2
tuberosity + tighbone wedge

Figure 7-3 : Dimensions for the foam cushions with a wedge construction.

Figure 7-4 depicts the 'pattern 4' foam composition. 'Pattern 4' more or less follows the pressure lines as expounded in literature. By cutting the foam not only does it make it softer, but it also inhibits the hammock effect from developing (see chapter 3.0). By using a range of different foam densities the reaction forces under deformation, and therefore the pressure-distribution, can be manipulated.

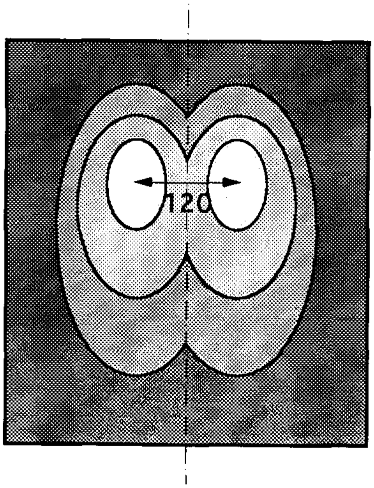


Figure 7-4: 'Pattern 4' foam composition.

Table 7-1 presents the results of a number of experiments next to each other. This clearly shows the influence of the equality factor EF on the overall results.

	PDQ	PD	EF	E1	E2	E3	E4	max. press. mmHg
DRAKA 9018, 80 mm without cover on trampoline	78	77	0.815	0.954	0.851	0.954	0.641	119
idem ditto on deformable support structure	77	77	0.797	0.995	0.924	0.757	0.712	124
foam wedge version 1, 80 mm thick, on trampoline without cover	88	80	0.882	0.999	0.885	0.989	0.772	93
idem ditto with thick fabric cover	80	78	0.821	0.990	0.872	0.922	0.667	108
pattern 4, 60 mm without cover on trampoline	81	78	0.828	0.933	0.836	0.964	0.683	108
cocohair PG 105C, 80 mm without cover on flat board	68	72	0.755	0.908	0.803	0.902	0.561	167
idem ditto on trampoline	86	80	0.855	0.997	0.877	0.885	0.803	106

Table 7-1 : Results of a number of experiments using different support structures and different pressure-distribution media.

A number of conclusions can be drawn from these design experiments: the deformable support structure improves the PDQ when compared with the results for the trampoline. Both support structures sag about 40 mm when subjected to a load. The PDQ result (78) is higher than for the target level for the high-risk user cushion (75).
The use of a wedge (version 1) shows an improvement of 10 PDQ points when compared to the non-manipulated DRAKA 9018 foam, from 78 to 88. This is an extremely high score, which is brought about to a large part by a high level of equality.The same cushion, when protected with a thick fabric cover, has a PDQ score of 80. Though the results can be considered to be still quite high, there is some hammock effect left.
The 'pattern 4' composition of 60 mm thickness on a trampoline without the cover also scores well with a PDQ of 81.

The last two cushions listed concern non-homogeneous vulcanised hair, that is, cocohair with a thickness of 80 mm, placed on a flat board and on a trampoline. In the first case the PDQ result of 68 can be viewed as favourable, when compared to the 80 mm DRAKA 9018 foam on a flat board which has a PDQ of 49 (see table 4-9). When placed on a trampoline a rise in PDQ of 18 to 86 results.
The conclusion from these figures is that vulcanised hair attains satisfactory to extremely good pressure-distribution results, at the same time probably enabling a number of other important cushion characteristics to be achieved, such as moisture and heat regulation.
The results of these experiments were used to design five so-called demo cushions. The cushions were constructed in such a way as to answer a number of specific research queries, among them how the important characteristics can be combined in a single cushion or what the specific influence of certain combinations of materials might be. These cushions together with their specific intention and their results will be discussed in more detail in section 7.2.

The rest of this section focuses on the results of two experiments carried out after the main cushion survey was concluded. The first experiment concerns an improvement in the size of the deformable support structure and the influence of sag on the pressure-distribution quality.
Figure 7-5 defines the dimensions of the improved deformable support structure. In fotograph 8 a picture is shown.

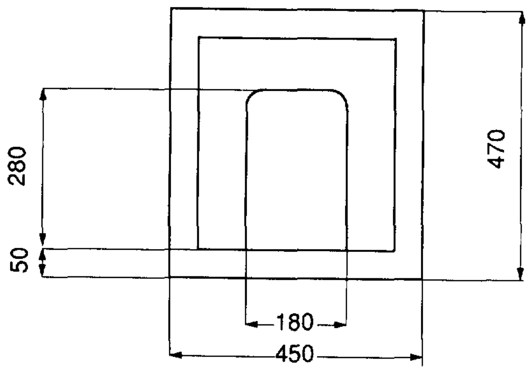
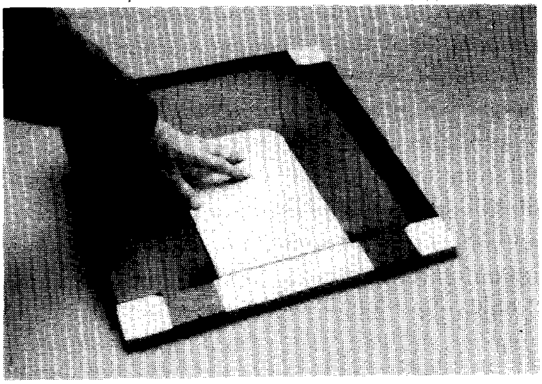


Figure 7-5 : Dimensions of the improved support structure (mm).



Photograph 8 : Deformable support structure: improved version

Table 7-2 presents the rather striking influence of the sag in the support structure. The table shows that the pressure-distribution for the deformable support structure with a 40 mm sag are the same as for the trampoline with the same sag. These results are also recorded for 80 mm foam (see table 7-1). The question therefore remains as to what extent the dimensions of the support structure have been improved.

The influence of sag on the overall result, however, is large. The 40 mm sag compared to the 30 mm and the 50 mm only seems to give an average result.

	PDQ	PD	EF	E1	E2	E3	E4	Max. press. mmHg
Demo D, non-homogeneous, vulcanised hair 60 mm thick on trampoline, with ± 40 mm sag	75	73.4	0.820	0.962	0.854	0.885	0.723	124
Demo D plus on improved deformable support structure with 30 mm sag	52	60.1	0.690	0.975	0.815	0.665	0.590	185
idem ditto, with 40 mm sag	75	74.0	0.814	0.975	0.871	0.868	0.704	130
idem ditto, with 50 mm sag	89	81.8	0.871	0.994	0.874	0.993	0.745	103

Table 7-2 : Experiments with an adjustable, deformable support structure in comparison to a trampoline using the same pressure-distribution medium.

The sag for the deformable support structure seems to have a considerable influence on the overall result. Not only does the pressure-distribution (PD) improve, but so does the equality factor (EF). It is an implausible proposition to suggest that the influence of a trampoline on the pressure-distribution quality: PDQ can be improved when the trampoline sags even further.

The second series of experiments attempted to optimise the effects of vulcanised hair as a pressure-distribution medium. Here cow-tail was used with a special rubber composition in two different thicknesses and two different finishes; a top layer which remained untampered with; and a top layer which was cut to a depth of 3 cm every 7 cm. In the latter case the top layer was cut in order to examine the hammock effect. The results are shown in table 7-3.

	PDQ	PD	EF	E1	E2	E3	E4	Max. press. mmHg
P9105J cow-tail XE, 60 mm thick without cover, on trampoline	84	78.8	0.848	0.961	0.868	0.989	0.688	104
idem ditto, with cuts 70 X 70 mm	90	82.8	0.873	0.965	0.902	0.943	0.772	89
P9105F special cow-tail XE, 80 mm thick without cover, on trampoline	86	81.5	0.842	0.953	0.916	0.888	0.723	99
idem ditto, with cuts 70 X 70 mm	90	79.8	0.903	0.901	0.915	0.957	0.838	87

Table 7-3 : Experiments with non-homogeneous vulcanised hair on trampoline in different thicknesses, with and without cuts.

The table shows that the cut versions have better results than those without cuts. Results for the non-incised cushions hardly show any improvement compared to the results of the experiments in table 7-3. What is striking, is the extremely high equality factor (EF) value (0.903) for the thick cushion with an incised top layer.

The general conclusion which can be made from these experiments is that the shape and sag of the support structure has a considerable influence on the pressure-distribution. By restricting the hammock effect the overall result can be influenced positively. By manipulating foam and vulcanised natural fibre, in conformity with the suppositions expressed in chapter 3.0, satisfactory to extremely good pressure-distribution results can be achieved. Compare in this respect the results of these experiments with the results in table 5-14, in which the scores are presented for the top 12 cushions. There are only two cushions which attain a PDQ value of 80 or more.

7.2 Purpose and design of the demo cushions

On the basis of the results gained from the initial experiments five demo cushions were designed, intended for specific user groups and with the aim of picking out particular aspects other than just pressure-distribution. These cushions were tested in the cushion survey. On the following pages are a number of photographs next to each of which is a short description of the cushion together with it's intended use and the specific research queries.

DEMO A

Composition

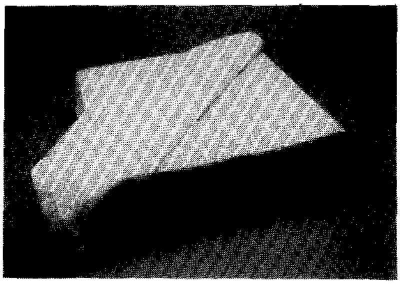
Cover:	pvc-vinyl
Top layer:	none
Pr. distr. medium:	cocohair PG 105 C 80 mm thick
Support structure:	trampoline, 40 mm sag

Intended use

Low-risk user cushion

Specific research queries

- What is the influence of cocohair on the heat regulation when using a pvc-vinyl cover ?
- What is the influence of cocohair on the shock absorption capacity ?
- What is the durability of cocohair ?



DEMO B

Composition

Cover:	'thick' stretch
Top layer:	none
Pr. distr. medium:	foam wedge version 2 DRAKA 9519/9529, 80 mm thick wedge/basis
Support structure:	trampoline, 40 mm sag

Intended use

Medium-risk user cushion

Specific research query

- What is the heat and moisture regulation of foam ?

DEMO C

Composition

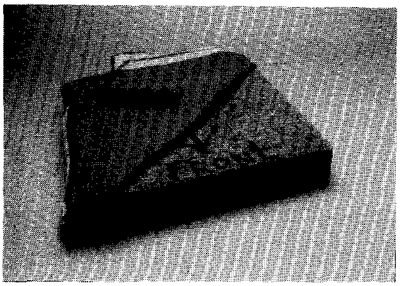
Cover:	thin stretch
Top layer:	incontinence absorption layer on hydrolon
Pr. distr. medium:	cocohair PG 105, A3
Support structure:	deformable support structure

Intended use

High-risk user cushion (incontinence)

Specific research queries

- What is the highest PDQ value to be attained regardless of the different top layers ?
- What is the effect of cocohair on the heat regulation ?



DEMO D

Composition

Cover:	thick woven woollen fabric
Top layer:	none
Pr. distr. medium:	cocohair PG 105 € 60 mm
Support structure:	trampoline, 40 mm sag

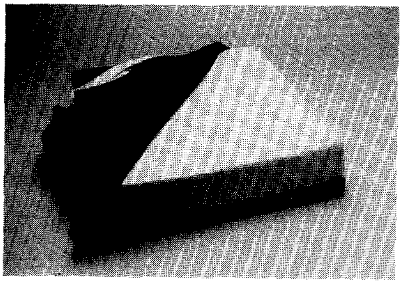
Intended use

Medium-risk user cushion (normal)

Medium-risk user cushion (transpiration)

Specific research query

- What is the maximum attainable moisture regulation ?



DEMO E

Composition

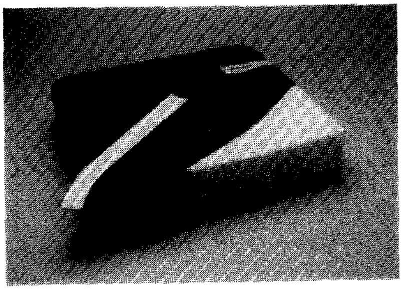
Cover:	'black' stretch
Top layer:	none
Pr. distr. medium:	foam/pattern 4
	outer : DRAKA 9518
	2 x inner : DRAKA 9519
	inner : DRAKA 8509
Support structure:	deformable support structure

Intended use

High-risk user cushion

Specific research queries

- What is the durability of 'pattern 4' constructions ?
- What is the maximum attainable PDQ ?



DEMO F

Composition

Cover:	thin stretch
Top layer:	none
Pr. distr. medium:	100 mm DRAKA 9018 foam
Support structure:	board

Intended use
for reference purposes

Specific research query
- How does 100 mm foam react on a board in comparison to other construction?

7.2.1 Results for the demo-cushions

The test results for the demo cushions were processed and presented in the same way as for the results for the commercially available cushions. This section interprets and discusses in detail the results of the characteristics which were examined specifically in relation to the research queries stated. The results are presented in table 7-4.

With the exception of the demo A and the demo F, all the cushions attain the highest target-level values, that is, 75 for the high-risk user cushion. On the basis of previous results this was to be expected, although in most cases covers were used which have some degree of influence on the pressure-distribution (see table 4-11, section 4.3). If the negative influence of pvc-vinyl on PDQ is taken into consideration - without pvc-vinyl, 78; with, 67 , then a score of 72 for the demo A cushion can be regarded as high. Despite the use of four layers (hydrolon, two absorption layers and a stretch cover) demo C cushion has a PDQ score of 79. Both for cocohair and for foam constructions, in combination with the support structures used, high PDQ values are achieved.

The heat-regulation values demonstrate that cocohair provides a clear improvement on foam. Section 1.4.2 discussed the readings of moisture and heat regulation taken for just one test subject. Demo D cushion scores twice as highly as demo F in respect of heat regulation. The demo A cushion scores considerably better as a result of using the pvc-vinyl cover. The structure of cocohair is so open that the air present evidently does not function as an insulator. In everyday wheelchair use the heat and moisture regulation will be increased on account of the vertical movements in the cushion, which introduces a constant supply of fresh air.

	demo A	demo B	demo C	demo D	demo E	demo F	
Composition							
cover	pvc-vinyl	stretch	abs. layer	fabric	stretch	stretch	
medium	cocohair	foam wedge 2	cocohair	cocohair	foam pattern 4	foam 100 mm	highest target-level
support struct.	tramp.*	tramp.	def.sup.	tramp.	def.	board	
PDQ	72	76	79	75	90	61	≥ 75 PDQ
stability	2.2°	5.0°	2.5°	2.1°	2.9°	5.6°	≤ 3°
moisture-regulation	28	64	64	232	144	154	≥ 175 $gr/m^2/24h$
heat-regulation	16	10	13	18	10	9	≥ 18 W/m^2
surface softness	81	28	66	44	19	41	≤ 50 mmHg
shock-absorption	311	251	273	369	243	277	≤ 280 N
durability	good	-	-	-	good	-	

* tramp. = trampoline
def. sup. = deformable support structure
underscored items relate to the specific research queries

Table 7-4 : Results of the sitting characteristics for the demo cushions in relation to the research queries.

The maximum target level of the shock-absorption capacity for the high-risk user cushion is ≤280 N increase in load and for the low-risk user cushion, ≤ 360 N, as a result of a free fall of 15 mm.
In all cases foam satisfies this norm. The deformable, springy support structure appears to have a positive influence. Cocohair for the demo A and the demo C cushion score < 360 N. It appears here too that the deformable support structure has a favourable influence. Demo F cushion does not attain the target level for the low-risk user cushion.

The durability of cocohair in particular formed a specific research query. Both cocohair and foam satisfy the tests and the assessment criteria in use. It must be stated however that the testing was not extensive due to a shortage of time. A possible future survey should therefore include more cycles and a higher load.

Although the demo cushions were not designed to optimise all characteristics, table 7-4 summarises the scores for the demo cushions for the different user groups with respect to each of the individual sitting and transfer characteristics

and to the overall score across these two groups of characteristics.
In this summary it would seem that it is possible to make a single cushion, which not only scores highly for a specific user group, but also scores highly for almost all the user groups. This might lead to a modification of either the assessment criteria or the definition of the user groups. Evaluation is necessary in order to establish exactly how these changes in definition might be made.

	low risk user cushion	med. risk user cushion	med. risk transpiration	high risk transpiration	high risk, incontinence
demo A	79 / 45 / 62*	72 / 65 / 69	(66 / 65 / 66)	(54 / 70 / 53)	(54 / 70 / 53)
demo B	77 / 45 / 62	67 / 51 / 61**	(61 / 51 / 57)	50 / 50 / 50	(50 / 50 / 50)
demo C	91 / 45 / 69	78 / 52 / 68	(72 / 52 / 64)	(57 / 54 / 56)	57 / 54 / 56
demo D	95 / 50 / 74	95 / 64 / 83	97 / 64 / 83	93 / 70 / 85	(93 / 70 / 85)
demo E	95 / 38 / 68	90 / 38 / 69	81 / 38 / 63	78 / 50 / 69	(78 / 50 / 69)
demo F	77 / 45 / 62	62 / 51 / 58	54 / 51 / 53	(30 / 34 / 32)	(30 / 34 / 32)
max. scores in study	64 / 93 / 77	56 / 86 / 68	62 / 70 / 65	72 / 41 / 62	62 / 34 / 53

* scores for sitting- and transfer characteristics and overall score respectively.
** underlined values relate to design purpose of cushion.
( ) does not satisfy threshold requirements, see table 6-11 in section 6.5.

Table 7-5 : Rounded-up overall scores for sitting- and transfer characteristics of the demo cushions and of both groups together, in relation to types of cushions and in comparison to the maximum scores in the study.

A general trend which table 7-5 shows is that the sitting characteristics of the demo cushions score more highly than the transfer characteristics and that the reverse is true of maximum scores in the cushion survey.
Although the correlation between the size of PDQ and the maximum indentation for all cushions in the survey appeared to be weak (0.462), the impression from the demo project is that there is a positive relationship between both phenomena, when the pressure-distribution quality is high as is the case for the demo cushions. This relationship may be dependent on particular types of solutions. The demo cushions were not optimised in their transfer characteristics. In general, the indentation of demo cushions is too high in relation to the assessment criteria developed. Since the demo cushions do have good scores in respect to pressure-distribution quality, the question can be raised as to whether both these characteristics can in all fairness be combined with each other and whether the part played by transfer characteristics in the overall results is not on the high side. The definition of 'sacral indentation' can

also be considered to be more critical in relation to the transfer function and in relation to the different cushion solutions. In the reference work, 'Voorstellen voor de beoordelingscriteria voor rolstoelkussens' (Staarink 1993) a number of proposals are made for modifying definitions, testing methods and weighted factors as a follow-up to this study.
Bearing in mind that not all characteristics can be optimised in the demo cushions, it can be concluded that it is very possible to realise the required sitting characteristics in one design.

7.3 A framework for cushion design

The first step in cushion design is to define the intended target group of users (see section 2.1.1). The assessment criteria for selected characteristics for the pre-defined user groups can be used as a basis for establishing specifications (see section 4.5 and 6.4). The weighted factors indicate the order of importance and can be used when compromises have to be made (see section 6.2).
Section 6.5.1 gave a summary of the influence of materials and constructions on the different cushion characteristics. This section also dealt with the reliability aspects of a cushion.
In choosing specific positive characteristics of materials and constructions the general implication is made that the negative characteristics need to be compensated for.
A satisfactory level of pressure-distribution is attained when a cushion is able to adopt (or conform) to the shape of the buttocks without the deformation of the cushion itself leading to high reaction forces. The shape of the support structure plays an important role in most systems. Tensile stress in the surface under load, referred to as the hammock effect, should be avoided. The more the support structure contributes to the conformity, the less the pressure-distribution medium needs to deform and - in the case of foam - the lower the relative deformation and the lower the chance of the hammock effect occurring. For air- and liquid-filled cushions it is important to keep the air- or hydrostatic pressure as low as possible. This is achieved by maximising the size of the surface under load and eliminating tensile stress in the surface of the sealing. Sections 3.0 and 5.0 analysed the advantages and disadvantages of the different systems in respect to their pressure-distribution performances. The different pressure-distribution systems each have their own specific effect on the sitting stability, the most important characteristic after pressure-distribution and after the heat- and moisture-regulation. Negative effects need to be compensated for.

7.4 Summary and conclusions

The experiments carried out, using a combination of different support structures and pressure-distribution materials, have shown that good to extremely good pressure-distribution can be achieved as long as a number of conditions are met. The contribution to the conformity of the support structure under load is highly important for the pressure-distribution materials and manipulations used. It has been shown that the depth of the shape of the support structure is a determining factor for a constant pressure-distribution layer. It is very plausible to optimise cushions individually by means of a correct manipulation of the depth of the support structure. No difference was shown between the results for the trampoline and those for the deformable support structure, when the depth of the shape is the same under load.
The objective of manipulations to foam and non-homogeneous vulcanised natural fibres are to achieve a minimum reaction force at the point where the largest indentation occurs. This is achieved by reducing the density of the pressure-distribution material on these placs. Since the shape of the support structure aims to realise a constant and minimum amount of indentation under load, the reduction in density eases the pressure in the area of the tuberosities, as can be observed from the satisfactory results gained from the experiments.

Combinations of desirable characteristics were analysed using a number of demo cushions. The good moisture- and heat-regulation properties expected of vulcanised natural fibres were indeed manifest, at the same time realising a good to extremely good pressure-distribution. Other positive characteristics, such as stability and surface softness, proved possible to realise. The shock-absorption level is indeed acceptable but requires further consideration at the cushion design stage.
Satisfactory to extremely good pressure-distribution can also be realised using foam. Weak points are stability and heat- and moisture-regulation. For both materials a good consistency of shape can also be achieved.
As a positive connection is likely between the indentation and the pressure-distribution, the question remains as to whether the current definition of the different indentation characteristics, the assessment criteria and weighted factors are indeed correct. There appears to be sufficient reason to make slight changes to these.
When compared to the demo cushions, the results for the commercially available cushions are disappointing, despite the claims made in manufacturers' literature. The commercially available cushions seem either to incorporate a predominantly traditional approach, or manufacturers are too inclined towards using a particular kind of pressure-distribution material - not however satisfying pre-defined specifications.

8.0 Review

The review of the survey will pay consideration to two important but distinctive questions. The first of these questions will consider whether the primary practical objective of the survey has been realised, that is, the aim of providing information to advisors in the field about the quality of wheelchair-cushions, so that the most appropriate choices can be made and cushions can be deployed in the best possible fashion. Inherent to this is whether a better understanding of pressure-distribution has been gained or whether this knowledge can be easily passed on.
The second question considers those points of criticism which can be made retrospectively about the survey or about the interpretation of the survey results. An attempt will be made in the following sections to answer these questions. The last section will offer suggestions for possible future study.

8.1 Applicability of survey results in practice

Much of this study was given over to an analysis of results into the quality of 47 different cushions tested comparatively under laboratory conditions. The cushions included standard wheelchair-cushions as well as so-called anti-decubitus cushions. To enable testing of the pressure-distribution quality of a cushion in laboratory conditions, an imitation model of a male pair of buttocks, fitted with 19 internal pressure sensors, was constructed and validated. The results and preliminary analyses of these investigations were previously expounded in three publications (Staarink, 1993) and were made available to GMD (Joint Medical Service) advisors and presented at special training sessions. Three workshops were also organised for external therapists and other consultants.

The aim of this study was to provide advisors with information in such a way that they might be able to choose the most appropriate cushion and deploy it in the best possible manner. The question can be asked whether this objective has been realised and, if not, what obstacles stood in the way.

A general problem arising from the results of this survey is that hardly any cushion can be described as the ideal one for any of the user groups. Although the Demo project showed that appropriate characteristics can simultaneously be combined in a single cushion, the mix of these characteristics in cushions currently available is evidently below par. The method used for developing threshold requirements, assessment criteria and weighted factors does indeed provide the highest score for a cushion, but this score is not sufficiently high and distinctive to facilitate an automatic choice of cushion. An overall result of 68% for the best medium-risk cushion in respect of sitting- and transfer-characteristics and a score of 67% for the next best cushion mean that, although the overall results for the cushions lie close to each other, they can have a totally different mix of characteristics. The advisors will therefore need to establish priorities per case themselves concerning characteristics. Other aspects, wich have not been included in the survey's overall assessment, such as past experience with a particular type of cushion, use with a particular wheelchair, price, maintenance, life expectancy, etc. will have to be taken into account in the advisor's overall assessment. For other types of cushion the highest overall results are below 68%; 65% for the medium-risk (transpiration) cushion; 62% for the high-risk user cushion; and 53% for the highest scoring high-risk user cushion (incontinence). This means that even fewer desirable characteristics have be realised and that even more priorities need to be established. This makes an easy interpretation of this survey somewhat complicated, especially if a set of unambiguous results had been expected from the survey.

Perhaps more important than the insight into the quality of currently available cushions gained during the study, is the applied scientific insight acquired into the way in which pressure-distribution is brought about by a cushion and how that affects the realisation of other desirable characteristics.
An examination was first made into the effects of the sitting posture on reaction forces which develop in a cushion due to the same sitting posture. The sitting posture determines in large part the size and direction of the external load which is exerted on the buttocks; the cushion determines the way in which these reaction forces are transmitted to the buttocks by means of pressure-distribution. The biomechanical aspects of pressure-distribution in the buttocks themselves and the effects of these on the development of decubitus have been analysed and used to interpret a good pressure-distribution when using a cushion. The most important principle in this respect is the ability of a cushion to preserve the original shape of the buttocks, i.e. as when not subjected to a load. A cushion is capable of doing this when the reaction forces in the cushion, due to its own deformation, are low enough at the point where conformity is realised. The shape of the support structure also plays a vital role in realising this conformity. The insight gained into the phenomenon of pressure-distribution enabled tools to be developed, which processed the results of 19 pressure sensors into a number on a scale of 0 to 100, and which could be used to make a comparative study of the pressure-distribution quality: PDQ of different cushions. A condition for using these comparisons correctly, is the realisation that the tests were carried out using an artificial pair of buttocks with a certain size, shape and structure and that the dimensions of the cushion under examination were, in principle, adapted to the dimensions of the test buttocks. For this reason the advisor in the

real world needs a basic understanding of the way in which different cushion systems work in order to be able to choose and deploy cushions effectively in individual circumstances. For every pair of buttocks possesses its very own pressure distributing capacity depending on the size, shape and structure of hard and soft parts which act in combination with sitting weight.
This was the reason for organising 3 workshops, at which the results and analyses were presented and elaborated upon. The 225 participants at these workshops were predominantly occupational therapists, physiotherapists, a number of specialist rehabilitation doctors and suppliers.
The 'knowledge', which advisors in clinical situations currently have at their disposal in respect of cushion quality, is for the most part based on 'experience'. For many of them literature does not provide a really useful reference guide in practice, since literature in general amounts to a listing of the experimental results rather than explanatory analyses. Often one is left to the prejudicial mercies of manufacturers' sales literature. In general, advisors tend to have experience using particular cushions, but are often not aware of their underlying principles. Practical considerations, such as matching the size of the cushion to the wheelchair, the 'washability' of the cushions and experience with life expectancy, usually form the basis for cushion selection in practice.
75 of the 225 participants at the workshops agreed to take part in a follow-up written evaluation which could be tied in with the results of the cushion survey. The aim of this feedback was to investigate whether the principles involved, i.e. definition of user groups, definition and testing methods for characteristics, the assessment criteria and the weighted factors, are acceptable or need to be modified.
This evaluation was divided into two parts. The first section was limited to a description of general impressions and the second section involved an evaluation on the basis of systematic case treatment using the pre-defined user groups. Participants themselves were asked in part one to enlist for part two of the evaluation. Part two of the evaluation has not yet been carried out due to lack of paticipantsnumbers.
Of the 75 original participants 28 evaluation forms were returned after reminders had been sent out. Though the willingness to take part in a feedback evaluation amounted to 33% of participants at the workshops, only 38% of this number (12% of the total number of participants) in fact chose to return the evaluation forms. Shortage of time was the most important reason for not responding to the feedback evaluation. In this and many other cases researchers are faced with a structural problem which prevents a satisfactory level of feedback from professionals in the field.
As to whether the general background information presented at the workshops was applied in practice, 32% answered in the affirmative, 21% said no and 40% more or less.
In reply to the question as to whether practical experience of working with cushions corresponded to the expectations which the results of the survey

generated, 64% answered positively, 22% had no opinion either way (yet) and 14 % answered no.
Most of those interviewed had not modified the methodology of their case treatment, taking into account the pre-defined user groups and corresponding cushion types. The impression is had that the user population in the nursing and rehabilitation clinics is considered rather specific by therapists working in them. The suggested approach therefore seemed to offer no new points of departure or advantages, with the effect that tried and trusted methods continued to be used. It appears that there is a tendency to maintain fixed procedures and to apply standard solutions.
Several different conclusions can be gathered from the 12% response of workshop participants and other reactions which were received. One particular group has a pressing need for practically-oriented, directly applicable information, e.g. "what is the best cushion?". This group has no wish to understand the material involved. The same group feels that the survey is not sufficiently practically-oriented since many of the commonly used solutions, e.g. an AD cushion *on* a 'standard', frequently used wheelchair-cushion were not investigated. Fortunately, another large group can be identified which recognises the fundamental character of the analyses. This group remains both enthusiastic and pleased with the relatively uncomplicated conclusions reached. They have attempted to understand the results of the analyses and put them into practice. They have accepted the necessary limitations of the survey and view the survey as a first step in the right direction. Whether this group is indeed able to apply this understanding in practice, raises a question which this evaluation cannot answer.

The question as to whether advisors and therapists on the basis of the information received can indeed select the most suitable cushion for an individual and use it correctly - the most important objective of this survey - can be answered, though cautiously, in the affirmative on the basis of this evaluation and the reactions given at the workshops.

8.2 Retrospective comments

The test buttocks showed their value in the analysis of the way in which the pressure-distribution of cushions works. The test buttocks appeared to be so sensitive that even the influence on internal pressure of a small thin OPM test cell with a diameter of 15 mm was shown to be significant. This test cell, with the exception of air-filled cushions with a divided surface, had a pressure increasing influence for all cushions. This means that, comparatively speaking, the interface pressure for the air-filled cushions is relatively favourable. It has already been established that in surveys the spread of test results for these cushions is always highest.

It is important to emphasise that the correlation between the PDQ and the maximum pressure recorded for the B2 test cell under the tuberosities is extremely high, at 0.966. The correlation between PDQ and the OPM data is also high (0.818). This fact enables the conclusion to be made that by measuring the pressure directly under the tuberosities a good impression can be gained of the achievable pressure-distribution per individual in practical situations. However, the measurement needs to be sufficiently accurate, which often forms a problem in real life situations.

The size of internal load is such that, even for the best cushions, it is considerably higher than the arterial pressure in the vascular system.
On the basis of this observation it is indeed astonishing that so few people develop decubitus instead of so many. Obviously, mechanisms are in play which maintain levels of nutrient supply to the cell whereby decubitus is prevented. This mechanism can only be put down to dynamics in the sitting process. Whatever else may be true, changes in external load denote changes in internal load, not only with respect to its size, but also to the direction of the internal forces. Internal shear forces can change direction as a result of these, and undesirable interstitial fluid flows may stop and can also change direction. In addition a pumping effect may be effectuated, due to the vessels being subjected to and then relieved of load, allowing the supply of nutrients to continue. For this last mechanism it is important that the vessels have in no way twisted closed.
In this respect it is also interesting to know at which pressure gradient (i.e the pressure difference measured between two different points on the buttocks) damaging effects in the tissue start to develop. If this phenomenon was known, the equality factor: EF could be validated.

The pressure-distribution quality value: PDQ of a cushion expresses comparatively the differences between cushions with regard to pressure distribution. It does not quarantee a good individual pressure distribution, because of individual differences. Therefore it is necessary to understand how pressure distribution is brought about by a cushion and to realize how it has been measured in order to adapt cushions properly to individual characteristics. The forecast value of the PDQ of a cushion might increase through comparative testing of a cushion on two pairs of test buttocks with different shapes and sizes.
Though cushions should be always optimised on an individual basis, some cushion systems facilitate this better than others. It might be viewed as one of a cushion's properties if it is capable of sustaining a satisfactory level of pressure-distribution for a large number of users.

The practicability of the survey results will increase when cushions, which meet all the assessment criteria specified for the acceptable level, become commercially available. This can be achieved by declaring the 0 level as the threshold requirement and defining approval guidelines on the basis of this. A careful analysis of current assessment and evaluation levels needs to be carried out beforehand. Given the reactions to the evaluation procedure described in this study, this can be achieved quickly and effectively with a panel of experts.
In this respect the results of the survey support the idea of a system for designating an 'anti-decubitus guarantee qualification'. This should be based on a homologation programme in which levels of pressure-distribution quality: PDQ have been set for defined user-groups.

The results of this survey contain many angles from which the quality of seating supports in general can be looked at critically and they provide a number of concrete procedures which can be easily improved. Whether it concerns wheelchairs, settees, or office furniture, aspects of sitting posture as well as the quality of seating supports can always be analysed on the basis of the same principles. Settees are generally 'soft' in nature, but they do not provide a good platform from which to achieve a good sitting posture and lumbar support in particular. The role of office chairs in providing a stable platform, from which a wide range of tasks can be performed, should also be considered. In addition to aspects of sitting posture, the seating support elements of office furniture can also be analysed with respect to pressure-distribution, sitting stability and heat- and moisture-regulation.

8.3 Suggestions for further study

The previous sections have raised a number of points which might form the subject of future research.
As an immediate follow-up action to this survey a number of items need to be further evaluated and if necessary modified: the pre-defined user groups, the characteristics selected, the methodology used, the assessment criteria and the weighted factors applied. On the basis of these modifications a homologation programme might be developed for wheelchair-cushions and an 'anti-decubitus' qualification could be given a protected status.

Future research can be improved by fitting test sensors symmetrically to the test buttocks and by constructing another version of test buttocks in which a high degree of atrophy can be simulated.
The method, according to which the test results were processed, can be enhanced considerably, when a link is made between the size of pressure differences and the damaging effects on tissue.

A better insight into the effects of alternating loads on tissue condition and on the preservation of nutritional processes in the tissue, might well contribute to the general understanding of decubitus prevention, to the development of good support elements and to the optimisation of sitting conditions.

Both office- and school furniture could form the subject of examination in respect of pressure-distribution quality and other important sitting characteristics, such as sitting stability and heat and moisture regulation.

Back and neck problems might be examined using a neurophysiological approach in relation to seated working. The effect of an instable platform, represented by a swivel seat, on the development of back troubles might receive special attention in this respect.
Sitting is an everyday phenomenon, but our insight into the relevant mechanisms, optimums and failures and our actual design traditions and guidelines, still show that there is much room for improvement and progress.

Sitting posture, Comfort and Pressure;
assessing the quality of wheelchair cushions

Summary and final conclusions

Traditionally, sitting is associated with status, furniture often being an expression of a person's social position. Not only does furniture afford status, but it also provides the basic structure for the sitting posture which is an expression of this status. The determining factor for the ergonomic function of a chair is the position of its supporting elements in space. A chair enables an individual to adopt, or may prevent him from adopting, a particular sitting posture. A relationship is said to exist between a particular activity and the posture - in this case sitting posture - which an individual assumes. Determining factors include an appropriate line of vision and proper eye-hand coordination as well as the amount of energy needed to maintain that sitting posture. Individuals tend to adapt their sitting posture intuitively according to the type of activity which is being carried out. Sitting postures can be interpreted by means of biomechanical and physiological analyses.

Where there is no requirement for continuous eye-hand co-ordination, a sitting posture is adopted which demands as little energy as possible to maintain. The location of the centre of mass for the whole of the upper half of the body, in relation to the assumed lumbar pivotal point, appears to be a main determining factor. An immobile lumbar spine, which is either straight or in kyphosis, has an assumed pivotal point under the ischial tuberosities. This can provide an inappropriate level of 'stability', as a result of a moment of force being exerted on the lumbar spinal column. This moment can lead to a progressive kyphosis of the lumbar spinal column.

To some degree the perception of comfort is determined by the position of the joints. The joints must occupy a 'central' position, in order for comfort to be perceived. Their position is determined by the length of the muscles on either side of the joint.

Where eye-hand coordination is required, a relaxed viewing posture adopted by the head will determine the sitting posture. This posture is necessarily 'active' on account of the line of sight required. This means that the stability of the upper half of the body must be maintained by muscle exertion.

The extent to which a sitting posture can be said to be suitable for a particular activity and the extent to which the chair or support is able to achieve this, are determining factors in the overall level of comfort experienced. In this respect comfort needs to be defined by the lack of discomfort, that is, an unpleasant feeling in the muscles, the joints, the skin and other elements of the human

physiological make-up. Discomfort arises as a result of excessive, incorrect or prolonged external load (or a combination of these), which in turn results in a perceptible internal load. The body responds to this, where possible, by modifying its sitting posture: a change in external load means an interruption of the time duration effect and a change in the size and direction of the internal load. The human physiology is not geared up to enduring static load for prolonged periods. On the contrary, it relies on movement. Activities ensure movement and furniture facilitates specific activities by affording the user appropriate changes in sitting posture.
Sitting posture - the position of the bodily segments in space - is for a large part responsible for the size and direction of the external load, due to the reaction forces of the seat on the body. Friction forces originating in the seat as a result of a poor sitting posture, are transmitted in the form of shear forces into the soft parts of the buttocks. Shear forces are perceived as being unpleasant since, in collaboration with the pressure, they quickly and effectively impede blood circulation.
A correct sitting posture can be defined as one which facilitates the carrying out of a particular task and where no friction forces are generated in the seat for maintaining the posture. The relationship between the seat angle, angle ϕ, and the angle between the seat and the backrest, angle α, appears to determine whether or not friction forces are brought about. For every angle α an angle ϕ can be found (and vice versa) where the friction forces are cancelled out. In such cases the reaction forces, with which the seating support responds as a result of the load, only occur in the form of normal forces as a result of the load. The way in which these normal forces exert themselves on the body is determined by the pressure-distribution capacity of the seat. The way in which the pressure-distribution operates defines the level of comfort which is perceived. As such, the seating support is not responsible for the size and direction of the load, i.e the sitting posture, but it does determine the way in which the load is transmitted into the buttocks.
The seating support can be looked upon as a 'platform' from which tasks are performed. A stable platform is essential in order to maximise eye-hand coordination. A non-stable platform can lead to fatigue and back trouble. As such, the position of head must be corrected each time when the upper half of the body modifies its position as a result of instability. The relative positions of the upper and lower halves of the body are also subject to constant correction, particularly in the lumbar region. The chair as a stable platform forms an underestimated aspect of sitting and of sitting problems. The sitting stability, which a seating support can or cannot offer, is very much a comfort-related characteristic.
The seating support is also responsible for the microclimatic conditions which prevail in the space between the seating surface and the buttocks. Reliable moisture- and heat-regulation characteristics of the seating support help increase comfort as well as prevent discomfort.

The neurophysiological aspects of sitting posture have a bearing on the role that the muscles play in maintaining the posture. The position of the head with the gaze directed at the horizon can be considered to provide a neurophysiological reference point from which correct muscle control must maintain a posture. Prolonged postures, where the gaze is not directed towards the horizon, can confuse the control mechanism and cause incorrect muscle exertion. This can lead to postural complications. The neurophysiological aspects of sitting posture should be given more consideration in ergonomics because many problems might have their origins here.

The validity of the analyses, which have been developed in respect of sitting and sitting posture, can be extrapolated to encompass persons who, on account of a functional impairment, can perform tasks from a sitting position only. Since normal-functioning body control mechanics may be lacking, individuals who are forced to adopt sitting positions 'permanently' are dependent on applying these principles correctly, in order to maintain an appropriate sitting posture. Good sitting postures, in terms of a correct positioning of angles ϕ and α, are an absolute precondition for this, as too are the ability to modify posture. In fact normal sitting behaviour needs to be emulated. Stability of the upper half of the body can be achieved by establishing a sufficiently large angle ($\phi + \alpha$). The shape and mobility of the lumbar spinal column have a role to play in achieving stability.

The quality of the seating support is especially important for wheelchair-users. The seating support not only affords comfort in as far as users can perceive this, but has a particularly important function in preventing decubitus. Decubitus develops as a result of prolonged, excessive or incorrect loads being applied to the tissue. In its development a large number of risk factors may come into play which may speed up this process. Decubitus is a result of the mechanical or physiological damage to cells, often in combination with each other. The lowest internally measured pressures under the ischial tuberosities are at least 3 times higher than the normal capillary pressure of 30 mmHg. This means a blockage of supply- and discharge- systems as a result of load during sitting. Long-term blockage can cause physiological damage to the cell. Localised high pressures can lead to acute mechanical damage to cells. A clinically established relationship is said to exist between the amount of external load - expressed as interface pressure - and the length of time. Since the interface pressure under the tuberosities indicates only half of the pressure which is exerted internally it is an astonishing fact that so few people actually develop decubitus. It would seem that regulating mechanisms and circumstances come into play which maintain the supply of nutrients and prevent damage. One of the control mechanisms might be that change of load, which in practice is almost always present, produces a pumping action from which temporary transport of fluids results. A precondition for this is that the vessels do not become twisted closed

as a result of excessive load. It is the shear forces in the tissue in particular which are held responsible for twisting vessels closed. The effects of time on the development of decubitus can be put down not only to the lack of nutrients supplied to cells, but also to the outflow of interstitial moisture between the cells when placed under a load. It is plausible to suppose that cells receive more mechanical damage more easily in this fashion.
The effect of load on the seating surface can be assessed on the basis of the skin's temperature response after being relieved of load.
The seating support is not only important in respect of good pressure-distribution but also for creating optimum conditions. Good moisture- and heat-regulation are also important elements in preventing decubitus. Natural sitting behaviour, where the sitting posture is adapted to suit the task being performed, will help further the essential dynamics of the load.

Each pair of buttocks appears to have its own unique pressure-distribution capacity, which is optimised when the shape of the buttocks remains the same when placed under a load.
The functioning of a cushion's pressure-distribution should aim to maintain the original shape of the buttocks as much as possible under load. An individual's own pressure-distribution capacity is dependent on the amount of soft tissue in the buttocks. The more there is, the higher the pressure-distribution capacity. A good cushion will adjust itself to the shape of the buttocks with the lowest possible reaction force. The shape of the cushion's support structure under load and the characteristics of the pressure-distribution medium are also determining factors.
There is a principal difference between the way in which foam works and the way in which air- and liquid-filled cushions function. Foam's deformation gives a reaction force which increases in proportion to the amount of deformation, i.e. indentation. The relative deformation appears to be important in practical situations. The level of reaction forces for air- and liquid-filled cushions depends on the size of the surface under load. The properties of the cover (and of the sealing in the case of air- and liquid-filled cushions) can influence the pressure-distribution in a negative way by the formation of tensile stress in the surface under load, in combination with the pressure-distribution medium. This phenomenon is known as the 'hammock effect'. This prevents the cushion from fully conforming to the shape of the buttocks. The tension in the surface under load can be averted by splitting up the surface into a number of smaller surfaces.

If the principles of a good sitting posture are directly applicable and extremely pertinent to individuals with an impairment, then the 'theory' developed for pressure-distribution is applicable in a direct and uncorrected way to whatever seating support.
The subtle principles and mechanisms, the aims of which are to prevent

decubitus amongst wheelchair-users, provide comfort when applied in normal chairs, in the sense that they prevent discomfort, i.e. an excessive, incorrect or prolonged internal load. The dining chair, the school bench, the office chair, the armchair, the wheelchair etc. can all be easily optimised on the basis of these principles of sitting posture and the seating support.

In order to measure the pressure-distribution of a seating support under laboratory conditions, an artificial pair of buttocks was designed and constructed, which resembled the shape, size and structure of male buttocks in a sitting position. It consisted of the buttocks plus the thighs. At strategic positions within this testing instrument, known as the test buttocks, 19 sensors were placed both on the 'pelvis' and underneath the 'skin'. Shape, size and load of the test buttocks were critical, because in comparison with the chosen load a relatively small amount of 'soft tissue' was used in the dummy. The test buttocks appeared to provide a sensitive, critical and accurate testing instrument, as indeed was the intention.

The test data was processed according to a method based in essence on the size: the extent to which the tuberosities are relieved of load, and on the quality of pressure-distribution: the equality of pressure-distribution which develops in the cushion. Pressure-distribution (PD) is defined as that percentage of load which is taken up by the buttocks with the exception of the area in the vicinity of the tuberosities. The equality of pressure-distribution is based on the pressure differences between four fixed positions in a cross-section of the test buttocks and is expressed as a factor between 0.4 and 0.9. The average of three of these factors is used as the equality factor (EF). The pressure-distribution quality (PDQ) is now defined as the product of both these indices, divided by 0.80. The origin of this 0.80 is the product of the highest PD value found during the survey, which was 85% and rounded up to 90%, and the highest EF found (0.9). The product of these two is 81, rounded down to 80. The PDQ is therefore a number on a scale from 0 to 100. This indicates the pressure-distribution quality of a cushion.

With the help of a panel of experts from a different backgrounds assessment criteria were systematically developed for three pre-defined user-groups and three sorts of use. This categorisation eventually led to the need for 5 different cushions:

- a low-risk user cushion for normal use;
- a medium-risk user cushion for normal use;
- a medium-risk user cushion for use in cases of excessive transpiration;
- a high-risk user cushion for normal use and for use in cases of excessive transpiration;
- a high risk cushion for use in cases of inconvenient incontinence.

On the basis of existing cushions, each of the panel members was asked to rate a cushion for a specific user group in relation to the suitability of a specific characteristic. In this way five types of cushions were designated, each group with its own specific mix of appropriate characteristics.
The assessment criteria for the pressure-distribution quality: PDQ were compared with the interface results recorded by Bar in his study. This was possible because the test buttocks were also fitted with sensors measuring interface pressure. The similarities of Bar's results and those for the assessment criteria in this study are surprisingly good, certainly when one takes into account the two totally different approaches.

The way, in which the pressure-distribution of different cushion systems works, can be interpreted on the basis of the following four questions:

- To what extent does the support structure contribute to the conformity with the shape of the buttocks? In other words to what extent will the pressure-distributing medium be indented, or - in the case of foam - what level of relative pressure will be produced?
- What is the link between the indentation and reaction force of the pressure-distributing medium being used?
- To what extent does an (undesirable) tensile stress develop in the surface under load in its entirety and what is the influence of the cover on this phenomenon?
- Is the principle of pressure-distribution capable of influencing localised reaction forces under the ischial tuberosities and is this principle applied?

The pressure-distribution performances for the 47 cushions in the survey cannot be regarded as particularly good. Only 6 cushions reached the target level, set for cushions in the highest risk group. Experimental results and the results for self-made demo cushions show that by applying the principles embodied in the four questions, results can be achieved which are either good or exceptionally good. The demo cushions were also designed to examine to what extent combinations of suitable characteristics could be realised simultaneously. This did in fact prove possible.
Cushion characteristics can be sub-divided into 'sitting' characteristics, 'transfer' characteristics and characteristics with respect to 'cleaning', 'reliability' and 'durability'. Other than pressure-distribution quality important 'sitting' characteristics include sitting stability, surface softness, shock-absorption capacity and heat- and moisture-regulation.
Important 'transfer' characteristics include smoothness, indentation, consistency of shape and creasing.

To be able to determine the overall quality of a cushion, not only did the assessment criteria in respect of the individual characteristics prove to be important for specific user groups, but also their collective importance in the

overall assessment.
These are the so-called weighted factors and are expressed as the percentage of the total share which any specific characteristic has in the overall result. In order to establish weighted factors, the panel of experts was once again enlisted to provide, in a systematic manner, assistance in the matter.

In principle both the test methods and the test instrument provided a suitable means for evaluating the characteristics of any seating support.

The principles established for good pressure-distribution of a seating support can indeed also be applied, with the necessary changes to detail, to lying supports. Any bodily part, which is supported in a lying posture, will possess its very own unique pressure-distribution capacity which can be best employed when its shape is maintained, just as is the case for the buttocks. Absence of soft tissue can lead to excessive pressure.

The quality of the wheelchair-cushions measured in this survey was, when considered against the importance of a cushion for an individual user, quite disappointing, especially as it has been proven that very good results can be achieved.

The price aspect has not as yet been a topic included in these analyses. What can be said, however, is that there is no positive link between a cushion's price and its quality. The demo project showed that exceptionally good results can be achieved using conventional and cheap materials.

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oktober 1995

Zithouding, comfort en druk;
beoordeling van de kwaliteit van rolstoelkussens

Samenvatting en eindconclusies

Zitten is vanoudsher geassocieerd aan status. Zitmeubels kunnen daar een expressie van zijn. Zij verschaffen niet alleen status maar ook de lichaamsondersteunende zithoudingen, die daarbij horen. Bepalend voor de ergonomische funktie van een zitmeubel is de stand van de ondersteuningselementen in de ruimte. Een zitmeubel maakt het mogelijk, of onmogelijk, bepaalde zithoudingen aan te nemen. Er blijkt een relatie te zijn tussen de soort aktiviteit en de houding, in dit geval de zithouding, die men daarbij inneemt. De gewenste kijkrichting en de gewenste mate van oog-hand coördinatie zijn bepalende faktoren, evenals de hoeveelheid energie die men kan of wil spenderen aan het handhaven van deze houding. Mensen blijken min of meer intuïtief hun houdingen steeds aan te passen aan de soort aktiviteit. Deze zithoudingen zijn goed door middel van biomechanische en fysiologische analyses te verklaren.
Is geen voortdurende oog-hand coördinatie vereist, dan wordt gezocht naar een zithouding die zo min mogelijk energie kost om deze te handhaven.
De ligging van het massamiddelpunt van het totale bovenlichaam ten opzichte van het modelmatige lumbale 'scharnierpunt' blijkt hierbij de bepalende faktor. Een immobiele lumbale rug, die over het algemeen vlak is of in kyfose, heeft een modelmatig scharnierpunt onder de tubera. Dit kan een 'stabiliteit' geven, die ongewenst is vanwege de introduktie van een momentbelasting op de lumbale wervelkolom. Dit moment kan leiden tot verdere kyfosering van de lumbale wervelkolom.
Het comfortgevoel wordt mede bepaald door de stand van de gewrichten. Deze hebben over het algemeen een als comfortabel ervaren 'midden' positie, die door de lengte van de spieren aan weerszijde van het gewricht wordt bepaald.
Is wel oog-hand coördinatie vereist, dan bepaalt de ontspannen kijkstand van het hoofd de zithouding. Deze houding is vanwege de vereiste bliklijn noodzakerlijkerwijs 'aktief', dat wil zeggen dat de stabiliteit van het bovenlichaam door spierinspanning gehandhaafd moet worden.

De mate van geschiktheid van een zithouding voor een aktiviteit en de mate waarin een zitmeubel deze houding mogelijk maakt, zijn bepalend voor de totale comfortbeleving. Comfort is in dit verband te definiëren als het ontbreken van discomfort: onaangename lichamelijke gevoelens in spieren, gewrichten, huid en andere lichaamssystemen. Discomfort komt door een te hoge, verkeerde en/of te langdurige, uitwendige belasting, die vervolgens voelbare inwendige belasting teweegbrengt. Het lichaam reageert daarop, indien mogelijk, met

houdingsverandering: verandering van de uitwendige belasting betekent een doorbreken van het tijdsduureffekt en tevens een verandering van grootte en richting van de interne belasting. De fysiologie van het lichaam is niet ingericht op langdurige statische belasting, maar is daarentegen afhankelijk van beweging. Aktiviteiten zorgen voor beweging, zitmeubels maken specifieke aktiviteiten mogelijk door het aanbieden van geschikte wisselende zithoudingen.
De zithouding, de stand van de lichaamsdelen in de ruimte, is in belangrijke mate verantwoordelijk voor de grootte en richting van de uitwendige belasting ten gevolge van de reaktiekrachten van de zitting op het lichaam.
Wrijvingskrachten, opgewekt door de zitting ten gevolge van een slechte zithouding, worden doorgegeven als schuifspanning in de weke delen van het achterwerk. Schuifspanning wordt als onaangenaam ervaren, omdat het tesamen met druk de bloedcirulatie sneller en effectiever blokkeert.
Goede zithoudingen kunnen gedefinieerd worden als zithoudingen, die een gewenste aktiviteit mogelijk maken en die geen wrijvingskrachten in de zitting opwekken om de houding te handhaven. De verhouding tussen de zithoek, hoek ϕ, en de hoek tussen zitting en rugleuning, hoek α, blijkt bepalend voor het al dan niet optreden van wrijvingskrachten. Bij iedere hoek α is een hoek ϕ te vinden, waarbij de wrijvingskrachten nul zijn en andersom. De zitondersteuning reageert in dat geval uitsluitend met normaalkrachten als reaktiekrachten tengevolge van de belasting.
De wijze, waarop deze normaalkrachten op het lichaam worden uitgeoefend, wordt bepaald door het drukverdelend vermogen van de zitting. De wijze van drukverdeling is zeer bepalend voor het comfortgevoel. De zitondersteuning is dus niet verantwoordelijk voor de grootte en richting van de belasting, dat is de zithouding, maar wel voor de wijze, waarop deze aan het achterwerk wordt doorgegeven.
De zitondersteuning kan ook worden beschouwd als een 'afzetvlak', vanwaaruit aktiviteiten worden uitgevoerd. Een stabiel afzetvlak is noodzakelijk voor nauwkeurige oog-hand coördinatie. Een niet-stabiel afzetvlak kan leiden tot vermoeidheid en rugklachten. De stand van het hoofd moet immers steeds worden gecorrigeerd wanneer het bovenlichaam tengevolge van de instabiliteit van stand verandert; ook de onderlinge stand van bovenlichaam en onderlichaam is aan voortdurende correktie -vooral in het lumbale gebied- onderhevig. Het zitmeubel als stabiel afzetvlak is een onderbelicht aspekt van het zitten en van de zitproblematiek. De zitstabiliteit, die een zitondersteuning al dan niet kan bieden, is een zeer comfortbepalende eigenschap.
De zitondersteuning is ook verantwoordelijk voor het microklimaat,dat tussen achterwerk en kussen ontstaat. Goede vocht- en warmteregulerende eigenschappen van de zitondersteuning verhogen het comfort, en voorkomen discomfort.
De neurofysiologische aspekten van de zithouding hebben betrekking op de wijze van aansturing van spieren bij het handhaven van de houding. De stand van het hoofd met de blik op de horizon gericht kan beschouwd worden als

neurofysiologische referentie houding, die zorgt voor een juiste aansturing van spieren. Langdurige houdingen waarin de blik niet op de horizon is gericht, kunnen het aansturingsmechanisme verwarren en voor foutieve spierspanningen in het lichaam zorgen. Deze kunnen leiden tot houdingsklachten. De neurofysiologische aspekten van de zithouding zouden in de ergonomie meer aandacht moeten krijgen, omdat veel klachten hier hun oorsprong kunnen hebben.

De geldigheid van de ontwikkelde analyses van 'het zitten' en 'de zithouding' is doorgetrokken naar mensen, die vanwege een funktiestoornis gedwongen zijn uitsluitend zittend te funktioneren.
Omdat normaal funktionerende regelmechanismen kunnen ontbreken, is deze groep door het permanente karakter van het zitten zeer afhankelijk van het juist toepassen van de ontwikkelde uitgangspunten voor een goede zithouding. Goede zithoudingen, in de zin van een juiste keuze van de hoeken ϕ en α, zijn hiervoor een absolute voorwaarde, evenals een veelvuldige houdingsverandering. In feite dient een natuurlijk zithoudingsgedrag nagebootst te worden.
Stabiliteit van het bovenlichaam kan verkregen worden door een voldoende grote hoek ($\phi + \alpha$). De vorm en mobiliteit van de lumbale wervelkolom spelen een rol in de wijze waarop de stabiliteit gerealiseerd wordt.

De kwaliteit van de zitondersteuning is vooral voor rolstoelgebruikers bijzonder van belang. De zitondersteuning biedt niet alleen comfort, voorzover door deze gebruikers waarneembaar, maar heeft vooral een belangrijke funktie in de preventie van decubitus. Decubitus ontstaat ten gevolge van een te langdurige, te hoge of verkeerde belasting van het weefsel. Op dit ontstaansproces is een groot aantal risicofaktoren van toepassing, die dit proces kunnen versnellen. De oorzaak van decubitus kan gevonden worden in een mechanische dan wel in een fysiologische beschadiging van de cel; meestal zullen ze in combinatie met elkaar voorkomen. De laagste inwendig gemeten drukken onder de tubera zijn tenminste een faktor 3 hoger dan de capillaire druk van 30 mmHg. Dat betekent dat aan- en afvoersystemen door de belasting ten gevolge van het zitten geblokkeerd worden. Langdurige afsluiting kan fysiologische schade van de cel tot gevolg hebben. Plaatselijke zeer hoge drukken kunnen leiden tot een acute mechanische schade aan de cel. Er blijkt een klinisch vastgesteld verband te zijn tussen de hoogte van de uitwendige belasting - uitgedrukt in de zogenaamde interface pressure- en de tijdsduur. Omdat de interface pressure onder de tubera slechts de helft van de druk, die er inwendig heerst, aangeeft, moet men vanuit dit verband verbaasd zijn dat zo weinig mensen decubitus krijgen, in plaats van zoveel. Er zijn dus kennelijk regelmechanismen en omstandigheden, die voedingsprocessen op gang houden en beschadigingen voorkomen. Een van die regelmechnismen zou kunnen zijn dat de dynamiek van de belasting, die er in de praktijk toch bijna altijd is, zorgt voor een soort pompwerking waarmee

tijdelijk vloeistoftransport op gang komt. Een voorwaarde hiervoor is wel dat de vaten tengevolge van de belasting niet dichtgeknikt zijn. Vooral schuifspanning in het weefsel wordt voor dat laatste verantwoordelijk gehouden. Het effekt van de tijdsduur op het ontstaan van decubitus zit niet alleen in het te lang ontbreken van voedingstoffen voor de cel, maar ook in het onder belasting wegstromen van het interstitiële vocht tussen de cellen. Denkbaar is dat de cellen hierdoor sneller mechanisch beschadigd kunnen worden.
Het effekt van de hoogte van de belasting op het zitvlak kan gemeten worden met behulp van de temperatuurreaktie van de huid na het opheffen van de belasting.
De zitondersteuning is niet alleen van belang voor een goede drukverdeling, maar ook voor het creëren van optimale omstandigheden. Vooral zijn een goede vocht- en warmteregulatie van belang bij de preventie van decubitus. Een natuurlijk zithoudingsgedrag, waarin de zithouding wordt aangepast aan de uit te voeren aktiviteit, bevordert de noodzakelijke dynamiek van de belasting.

Ieder achterwerk blijkt een eigen uniek drukverdelend vermogen te hebben, dat optimaal wordt benut, wanneer de vorm ervan onder belasting gehaafd blijft.

De drukverdelende werking van een kussen dient er dus op gericht te zijn de vorm van het achterwerk onder belasting zo goed mogelijk in stand te houden. Het eigen drukverdelend vermogen is afhankelijk van de hoeveelheid weke delen. Hoe meer daarvan aanwezig, deste hoger het drukverdelend vermogen. Een goed kussen neemt de vorm van het achterwerk aan, met de laagst mogelijke reaktiekrachten. De vorm van de draagconstructie onder belasting en de eigenschappen van het drukverdelend medium zijn hierin bepalende faktoren.

Er is een principieel verschil in de werking van schuim en de werking van lucht- of vloeistof gevulde kussens. De vervorming van schuim geeft een reaktiekracht, die groter is naarmate de vervorming, in de zin van indrukking, groter is. In concrete toepassingen blijkt de relatieve vervorming van belang. De reaktiekracht van lucht- of vloeistofgevulde kussens hangt af van de grootte van het belaste oppervlak, dat onder belasting ontstaat.
De eigenschappen van de cover of van het omhulsel, in geval van lucht- of vloeistof gevulde kussens, kunnen de drukverdeling negatief beïnvloeden, doordat ze onder belasting in samenwerking met het drukverdelend medium een trekspanning in het belaste oppervlak teweeg kunnen brengen. Dit verschijnsel staat bekend als het 'hangmat' effekt. Het staat een volledige conformiteit met de vorm van het achterwerk in de weg. De trekspanning in het belaste oppervlak kan bij alle typen kussens worden voorkomen door het belaste oppervlak in kleine oppervlaktes op te delen.

Zijn de ontwikkelde uitgangspunten voor een goede zithouding direkt en bij uitstek van toepasing op mensen met een funktiestoornis, andersom is de

ontwikkelde 'theorie' van drukverdeling direkt en ongecorrigeerd van toepassing op welke zitondersteuning dan ook.
De subtiele principes en mechanismen, die tot doel hebben om decubitus bij rolstoelgebruikers te helpen voorkómen, zorgen, toegepast in gewone stoelen, voor comfort, omdat ze discomfort, lees: te hoge, verkeerde of te langdurige inwendige belasting, voorkomen. De keukenstoel, schoolmeubilair, werkstoelen, kantoorstoelen, fauteuils, rolstoelen, banken etcetera zijn vanuit de aangedragen analyses eenvoudig te optimaliseren met betrekking tot zithouding en zitondersteuning.

Om de drukverdelende werking van een zitondersteuning in een laboratoriumsituatie te meten, is een kunstmatig achterwerk ontwikkeld, vergelijkbaar met de vorm, maat en struktuur van een zittend mannelijk achterwerk, bestaande uit de billen en de bovenbenen. In dit meetinstrument, meetbil genoemd, zijn op strategische plaatsen op het 'bekken' en achter de 'huid' 19 druksensoren aangebracht. Vorm, maat en belasting van de meetbil zijn kritisch, dat wil zeggen dat er relatief weinig weke massa is bij de gekozen belasting. De meetbil blijkt een gevoelig, kritisch, zoals bedoeld, en nauwkeurig meetinstrument te zijn.

De meetgegevens zijn verwerkt volgens een methode, die is gebaseerd op de essentie van de grootte: de mate, waarin de tubera niet worden belast, en van de kwaliteit van drukverdeling: de gelijkmatigheid van drukverdeling die door het kussen ontstaat. De drukverdeling: DV wordt gedefinieerd als het percentage van de belasting, die door het achterwerk met uitzondering van twee kleine gebieden rondom de tubera wordt opgenomen. De gelijkmatigheid van drukverdeling is gebaseerd op het drukverschil tussen 4 gedefinieerde plaatsen in de dwarsdoorsnede van het achterwerk en wordt uitgedrukt in een faktor tussen 0.4 en 0.9 . Het gemiddelde van drie van deze faktoren wordt als de gelijkmatigheidsfaktor GMF gehanteerd.
De drukverdelingskwaliteit DVK wordt nu gedefinieerd als het produkt van deze beide kengetallen, gedeeld door 0.80 . Deze 0.80 komt voort uit het produkt van de hoogst gevonden waarde van de DV in het onderzoek, die 85 % bedraagt en afgerond is naar 90 % , en de hoogste waarde van de GMF die 0.9 bedraagt. Het produkt is derhalve 81, afgerond tot 80.
De DVK is derhalve een getal, dat op een schaal van 0 tot 100 de drukverdelingskwaliteit van een kussen weergeeft.

Met behulp van een panel van praktijkdeskundigen van verschillende disciplines zijn op een methodische wijze beoordelingscriteria ontwikkeld in relatie tot drie gedefinieerde gebruikersgroepen en drie soorten van gebruik.
Deze indeling heeft uiteindelijk geleid tot de behoefte aan 5 verschillende kussens: (ad = anti-decubitus)

- een verzitkussen voor normaal gebruik;
- een ad-verzitkussen voor normaal gebruik;
- een ad-verzitkussen voor gebruik bij overmatige transpiratie;
- een ad-stilzitkussen voor normaal gebruik en voor gebruik bij overmatige transpiratie;
- een ad-stilzitkussen voor gebruik bij hinderlijke incontinentie.

Aan de hand van bestaande kussens heeft elk van de panelleden keuzen gemaakt ten aanzien van de geschiktheid van een bepaalde eigenschap van dat kussen voor een bepaalde gebruikersgroep. Op deze wijze zijn vijf typen kussens 'samengesteld', ieder met een specifieke mix van gewenste eigenschappen.
De beoordelingscriteria voor de drukverdelingskwaliteit zijn vergeleken met de interface-resultaten, die de engelsman Bar in zijn onderzoek heeft gekregen. Dit was mogelijk, omdat met de meetbil ook een meting is uitgevoerd, die de interface-pressure heeft vastgelegd. De overeenkomst tussen de resultaten van Bar en de ontwikkelde beoordelingscriteria is verrassend goed, zeker wanneer de twee totaal verschillende benaderingen in aanmerking worden genomen.

De drukverdelende werking van de verschillende kussensystemen blijkt goed verklaard te kunnen worden aan de hand van de beantwoording van de volgende vier vragen:

- In welke mate draagt de draagconstructie bij aan de conformiteit met de vorm van het achterwerk? Met andere woorden, in welke mate zal het drukverdelend medium ingedrukt worden of -in geval van schuim - welke relatieve indrukking zal er ontstaan?
- Hoe is het verband tussen indrukking en reaktiekracht van het toegepaste drukverdelend medium?
- In welke mate ontstaat er een (ongewenste) trekspanning in het belaste oppervlak als geheel en wat is de invloed van de cover op dit fenomeen?
- Staat het drukverdelende principe toe ter plekke van de tubera de reaktiekrachten te beïnvloeden en is dat toegepast?

De resultaten van de drukverdelingskwaliteit van 47 onderzochte kussens zijn niet onverdeeld gunstig te noemen. Slechts 6 kussens voldoen aan het streefniveau van het kussen voor de grootste risico groep.
De resultaten van experimenten en van ontwikkelde demo-kussens laten zien dat met de toepassing van de pricipes uit bovengestelde vragen goede tot zeer goede drukverdelingsresultaten zijn te behalen.
De demo-kussens zijn ook ontwikkeld om te onderzoeken in hoeverre combinaties van gewenste eigenschappen gelijktijdig te realiseren zijn.
Onderzocht is of met gerubberiseerde natuurlijke vezels, die goede vocht- en warmteregulerende eigenschappen hebben, ook een goede drukverdeling te realiseren is. Dat blijkt het geval te zijn.

De eigenschappen van een kussen zijn verdeeld in 'zit-eigenschappen' , in 'gaan-zitten-eigenschappen' en de eigenschappen met betrekking tot het 'schoonmaken', de 'bedrijfszekerheid' en de 'duurzaamheid'.
Typische ziteigenschappen naast de drukverdelingskwaliteit zijn: de zitstabiliteit, de oppervlakte zachtheid, het schokabsorptie vermogen en de vocht- en warmteregulatie.
Bij de gaan-zitten-eigenschappen zijn vooral de gladheid, de indrukking, de vormvastheid en de plooivorming van belang.

Om de kwaliteit van een kussen te kunnen vaststellen, zijn niet alleen de beoordelingscriteria van de afzonderlijke eigenschappen in relatie tot een specifieke gebruikersgroep van belang, maar ook hun onderlinge belang in de eindbeoordeling. Dit zijn de zogenaamde weegfaktoren. Ze worden uitgedrukt als een percentage van het aandeel dat desbetreffende eigenschap in het eindoordeel heeft.
Voor het vaststellen van de weegfaktoren is ook het panel van praktijkdeskundigen op methodische wijze geraadpleegd.

De ontwikkelde meetmethoden en meetinstrumenten zijn in principe geschikt om de eigenschappen van elke zitondersteuning te meten.

De ontwikkelde uitgangspunten voor een goede drukverdeling van zitondersteuningen zijn mutatis mutandis uiteraard ook van toepassing op ligondersteuningen. Ieder lichaamsdeel, dat in de lighouding ondersteund wordt, zal zijn eigen uniek drukverdelend vermogen hebben, dat op dezelfde wijze als bij het achterwerk het beste wordt benut, wanneer de vorm ervan intakt gehouden wordt. Afwezigheid van voldoende weke massa kan leiden tot hoge drukken.

De vastgestelde kwaliteit van de onderzochte rolstoelkussens is, in het bijzonder vanwege het belang voor de individuele gebruiker, nogal teleurstellend; zeker nu is aangetoond, dat zeer goede resultaten te bereiken zijn.

Het kosten aspekt van de kussens is tot nu toe in de analyses niet betrokken. Hier kan gesteld worden dat er geen positief verband is tussen de hoogte van de kostprijs en de kwaliteit van een kussen. Het demo-projekt heeft ook laten zien dat met conventionele en goedkope materialen zeer goede resultaten zijn te bereiken.

H.A.M. Staarink, oktober 1995

Curriculum vitae

Henricus Antonius Maria Staarink was born in Doesburg, the Netherlands on 2 February 1946. After gaining his Gymnasium ß diploma in 1966 he commenced a degree in physics at the Delft University of Technology before taking up studies at the Industrial Design Engineering department in 1967, which he completed in 1974. His final year project involved the development of a universal wheelchair system together with W. Muller on request of the Stichting Revalidatie Research. He continued working on the project after completing his studies. Together with the physiotherapist, A. Tournier, a large number of sitting experiments were carried out on a range of disabled persons at 'Het Zonnehuis' nursing clinic in Vlaardingen. Here a basic insight was gained into the effects of sitting posture in curbing the development of spasticity. By the end of the project a prototype of the seating unit had been developed as well as a dummy version of the chassis. Due to lack of resources necessary to continue the project the author took on a staff position at the Gemeenschappelijk Medische Dienst (Joint Medical Service) in 1976 where he was able to further develop the expertise which had been gained with regard to sitting. Wheelchair user groups were defined and assessment criteria (e.g. seating dimensions) for wheelchairs developed, which eventually led to approval specifications for wheelchairs.

In cooperation with the Revalidatie Instituut Muiderpoort he also managed a number of product development projects, including an innovative hoist and a demonstration model of a wheelchair with two settings. In 1986 the first attempts were made to define user groups for wheelchair cushions in partnership with experts in the field. In 1988 the first experiments were carried out using a test simulatos of sitting buttocks. In 1990 a research programme with respect to wheelchair cushions was launched at the TNO Textile Centre. The first reports of this programme were published as product information and the research findings presented at three workshops in 1993.

His last major piece of work for the GMD, together with F. van Haaster, was the publication of 'Het Zitboek, zithoudingsproblematiek in rolstoelen', an analysis of sitting posture problems for wheelchair users. As a result of changes in legislation regarding the provision of equipment for the disabled, the activities of the GMD and its staff were no longer required.

The author is now a freelance researcher, designer and consultant.

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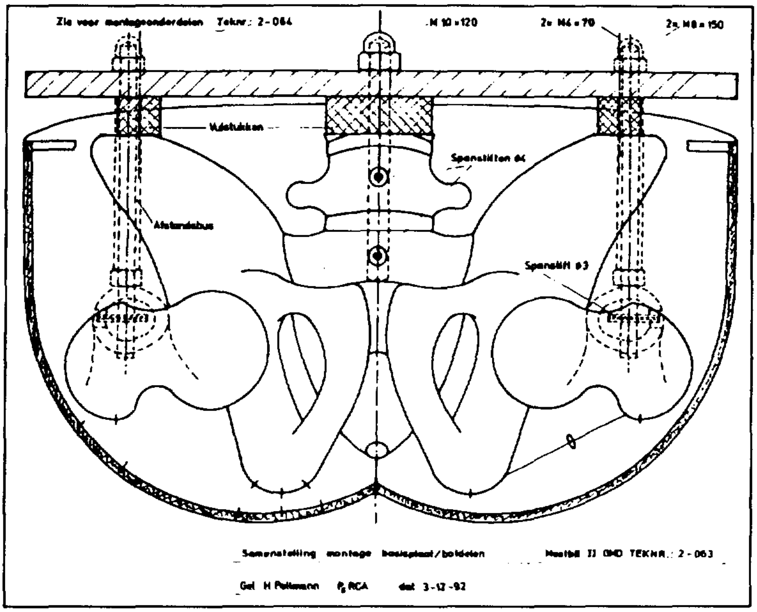
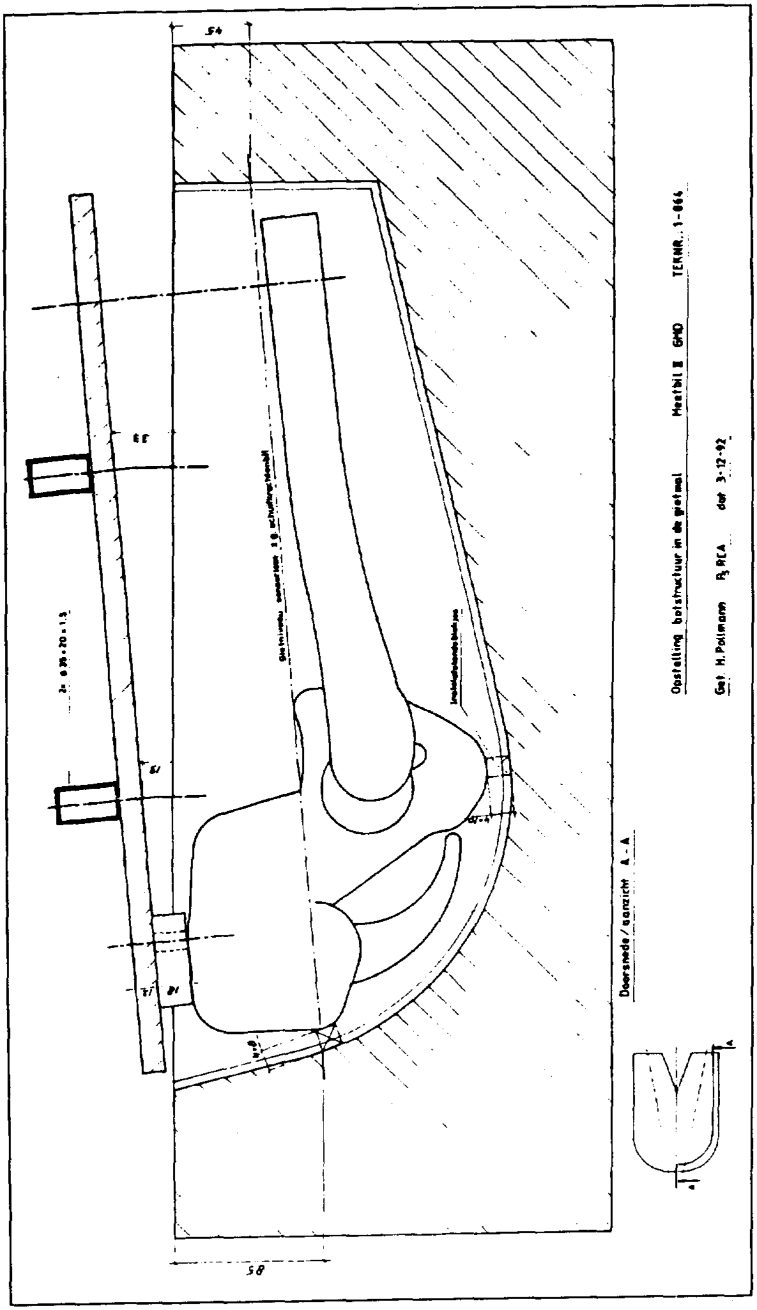
Appendix 1



Cross-section of test buttocks



Test buttocks in mould