AN INVESTIGATION INTO THE ERGONOMICS OF STANDING

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Thesis Presented for the Degree of
DOCTOR OF PHILOSOPHY
in the Department of Biomedical Engineering
UNIVERSITY OF CAPE TOWN
February 1996

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INTRODUCTION TO THE THESIS :

"An investigation into the ergonomics of standing."

Standing sets man proudly apart from the other animals. The word "stand" is associated with strength, steadfastness, solidity and integrity as in "stand by", "take a stand on", "stand in good stead" and "stand one's ground". It rings far more positively than words like "squat", "crouch" and even "sit". There is something powerful about planting one's feet on the ground and drawing oneself up to one's full height.

The motivation for this thesis grew out of the recognition that, as ubiquitous as upright standing is, it is something largely taken for granted, much like respiration. The thesis begins with a review of literature on aspects of standing, many not specifically related to man in the workplace, but all important in that wherever human beings are standing these aspects have relevance. In the course of the review it becomes clear that the act of standing is highly complex and that where workers are standing, a large range of variables are at play. Ideally, design of workplaces for standing workers should be able to factor in all or many of these variables although in practice this is not possible.

A survey of standing workers at five different sites was conducted in order to provide a broader background for the laboratory studies which followed. This survey involved a relatively small number of workers but it clearly suggested that prolonged standing is related to musculoskeletal discomfort and that this may be exacerbated by additional postural stresses due to other workplace variables.

The survey was followed by two laboratory studies using stereophotogrammetry to record postural adaptations to workplace modifications in standing work. The first study involved workers working at a light task and the second involved work at a VDT. Both studies emphasised the importance of foot position as a factor influencing the posture of standing workers, reinforcing recommendations made by researchers up to 80 years ago but which have not been taken up and which do not feature strongly in the literature on ergonomics. In addition, it was possible to establish within a high degree of accuracy that altering workplace variables had a very significant effect on the resultant postures. These studies also served to show that stereophotogrammetry is an excellent and much under-used tool for the study of posture by ergonomists.

Having explored the relationship between standing work and musculoskeletal discomfort to some extent, both in the field and in the laboratory, the thesis then evaluates whether the use of "standing aids" has any effect on reducing discomfort in prolonged standing. This study produced interesting results, especially regarding the patterns of interaction between the subjects and the standing aids.

The thesis therefore investigates the ergonomics of standing using a variety of approaches and, as a result, some recommendations about standing work can be made. However, the combined conclusions of all the studies draw into question the appropriateness of standing as a habitual arrangement, and the wisdom of allowing prolonged standing in the workplace without very carefully developed guidelines.

It is the hope of the author that the work presented here will contribute to a basis for further much needed research on standing work. It is only through further research that guidelines can be developed to ensure that the standing worker works under the least amount of strain. As a result he or she will be less likely to develop any of the afflictions with which prolonged (especially static) standing has been linked.

ACKNOWLEDGEMENTS

I would like to acknowledge the contribution of the following with gratitude:

The Medical Research Council of South Africa who provided financial support for this work for two years.

My supervisors, Dr R.S. Bridger and Professor L.P. Adams for their interest, encouragement and support.

Mrs Barbara van Geems who wrote the software producing the three-dimensional co-ordinates and provided cheerful support in all other stereophotogrammetric matters.

Mr John Ireland who to built the control frame and the standing aids efficiently and skilfully.

Mr Peter van den Berg for his clear-sighted and practical assistance.

The staff and students in the Department of Biomedical Engineering for providing the congenial background against which this work proceeded.

All the long-suffering subjects who stood for hours puzzle-building, working at the VDT or watching videos.

My mother, Mrs Elise Foster, for her unfailing support and hours of baby sitting.

This dedicated to Douglas and Desmond who inspire me

"And that has made all the difference"

Robert Frost

ABSTRACT

The work for this thesis can be divided into five parts :

Part I - A review of standing

This section examines the literature on standing and attempts to build up a comprehensive picture of what happens when a human being stands upright. The review starts by exploring those changes to the skeleton and musculature which have enabled homo sapiens to be erect. This is followed by a look at how humans maintain upright posture through postural control and the role of the 'anti-gravity muscles'. Postural sway is inherent to standing and this is examined in some detail along with the concepts of centre of foot pressure and effective foot base.

Attention is drawn to the fact that the subtleties of the upright posture are largely determined by culture and background. Foot position largely determines the quality of upright posture and this concept is explored in some detail. There are quantifiable physiological changes which occur when going from a supine position to an upright position and the review covers a comprehensive examination of these. In addition, the phenomenon of postural stress is also discussed. Besides postural sway, people move while standing and various reasons for changing postures are presented. The review also examines asymmetry, an inherent aspect of standing.

Finally, research on standing in the workplace is discussed. It is clear that the area is under-researched. Much work on standing was done earlier in the early part of the century and then again 40 and 50 years ago. Very little of this early research has penetrated ergonomics. By contrast, there is a vast body of accepted research on seating which is applied in ergonomics. This review seeks to present knowledge about standing which may be applied in the context of ergonomics. The preceding review underscores the importance of focusing on the standing worker who must simultaneously contend with multiple variables like

gravity, culture, workplace constraints, physiological changes and bodies which have not evolved for many of the postures imposed on them.

Part II - a survey of standing workers at five different sites

This survey aimed to provide a practical motivation for the following three studies (Parts III - V). It sought to explore how standing workers operate, how workplace variables affect perceived discomfort, when the onset of discomfort is detected and where in the body this discomfort is experienced.

A total of 68 subjects, employed in various occupations at five different sites, were observed and interviewed. It was determined whether subjects ever assumed constrained or prolonged static postures during the working day, whether they assumed postures which required unnatural joint angles, whether they used high velocity repetitive movements and whether their jobs entailed any lifting and carrying. They were also asked how long they stood every day, when they became aware of discomfort, where this was felt and how severe it was.

The results showed that there was a large variation across sites in all aspects. In general, however, severity of discomfort had a high association with hours before detection of discomfort, especially when workers performed lifting and carrying tasks. The lower back was the chief area of discomfort, especially among those who detected the onset of discomfort later. Where discomfort was reported earlier, this discomfort tended to be in the legs and less severe. The data also suggested that workers who walked in between standing suffered less discomfort.

Part III - Postural adaptations to workbench modifications in standing workers

The aim of this study was to investigate postural adaptations in constrained standing to facilitate the development of design guidelines for standing workspaces. Standing postures were observed in six different workspaces which were designed using combinations of task distance (which was constrained or unconstrained) and foot position (which was constrained, unconstrained or employed a footrest).

Subjects at work were recorded stereophotogrammetrically and postural variables were obtained in three dimensions. Postural adaptation to increased task distance was found to be characterised by increased trunk flexion and increased hip flexion while adaptation to close work was found to be characterised by increased neck flexion and increased thoracic kyphosis. Constrained foot position resulted in increased hip flexion accompanied by increased plantar flexion. Although use of the footrest resulted in some reduced lumbar lordosis, it increased trunk flexion and was not associated with significantly less discomfort than any of the other workspaces.

Part IV - Adaptations to standing VDT work

A laboratory study was conducted in order to investigate postural adaptations to constrained standing during VDT work sessions. Standing posture was observed in six different workspaces which were designed using combinations of foot position (which was either constrained or unconstrained) and varied VDT screen height.

Subjects at work were recorded stereophotogrammetrically and postural variables were obtained in three dimensions. Postural adaptation was found to be significantly asymmetrical with the weight carried on the left. The constrained foot position resulted in more bending forward from the hip. Raised screen height resulted in decreased neck flexion and increased hip flexion.

It was concluded that recommendations for seated VDT work are not always applicable to standing VDT work.

Part V - Evaluation of standing aids for the workplace

Providing some degree of support to standing workers while still enabling them to be upright and able to work may help to prevent or alleviate some of the problems

related to prolonged constrained standing. This study examined the use of three standing aids to determine whether subjects with access to these aids experienced significantly less discomfort than a control group. The results showed that those subjects using the footrest suffered less discomfort that the control group. Subjects using the other standing aids were no more comfortable than the control group although interesting patterns of interaction with the aids emerged.

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1 - A REVIEW OF STANDING

Any study of standing has to begin with two questions: why are we bipedal and what adaptations have enabled us to stand?

Most monkeys and all apes can assume a fully erect posture - monkeys for a quick orientation at a higher level and apes for a limited bipedal walk or run, to free the hands for fighting, to carry some large item of food or to support helpless offspring. (Schultz, 1969) However, the hominids have been walking upright for at least 3.5 to 4 million years and "man is the only primate able to stand fully erect for long periods of time, with full extension at the knee-joint and minimal expenditure of muscular energy" (Tobias, 1982, p. 14). Bipedalism is unequivocally one of man's main distinctions.

Figure 1.1 Female orang-utan carrying its young in both of its hands (after a photograph of a captive animal) (From Schultz, 1969)

Many scientists have examined the advantages of habitual bipedalism on the assumption that a trait must have advantages to evolve and survive. Napier (1967) argued that man's ancestors found their way into the Miocene woodland savannah where food was scarce. They made the transition to bipedalism as freeing of the hands meant that when food was found, it could be carried readily from one place to another for later consumption. Lovejoy (1981) hypothesised that a male that was able to provision a female with food had a reproductive advantage.

Washburn (1967) argued that human walking was an adaptation to cover long distances economically. This would have been a great asset for food gathering when food became more dispersed. Morris (1967) suggested that the ancestral apes' need for animal protein put strong pressure on them to improve their skills as predators. As a result, they became upright and better at running. At the same time, their hands became freed to become strong and efficient weapon holders.

Schultz (1969) considered the freeing of the upper extremities for "new functions" to be one of the biggest advantages of bipedal locomotion. It was suggested that bipedalism was essential for the emergence of tool-making activities (Vevers and Weiner, 1963). Tobias (1982) however pointed out that tool-making and tool-using are also possible for an animal that is sitting upright. Standing upright is not essential for these activities. Although some theories are more plausible than others, it is likely that there was no single factor responsible for man's upright stance. What there is no doubt about is that the approach was tried, found to work and adopted.

Despite complex anatomical adjustments affecting every part of the skeleton and locomotor apparatus, the mechanism of man's upright posture is by no means perfect as indicated by the prevalence of "flat feet, slipped discs, hernias, prolapses and malposture" (Tobias, 1982, p. 10)

1.1 Anatomical adjustments

These anatomical adjustments can be examined in two groups - changes to the bones and changes to the musculature. Changes to the skeleton have been studied more intensively as fossil skeletons can be directly compared with those of recent primates. The adaptations to convert a quadrupedal ape into a bipedal hominid occurred mainly in the pelvis, the femur and the foot. However, while the literature emphasises changes in the mechanical and functional requirements of the bones of the lower limb, important changes also took place in the axial skeleton.

The skull : Enlargement of the brain and shortening of the muzzle meant that, for the bipedal hominid, the centre of gravity of the head shifted more nearly over the point of support . As a result, the head articulates with the atlas, compressing the cervical vertebrae, unlike the hanging head of the quadruped. The occipital condyles have moved anteriorly and the post-vertebral muscles, now only required for poise of the head, have a much smaller attachment area on the skull. (Tobias, 1982) (Palastanga et al, 1989)

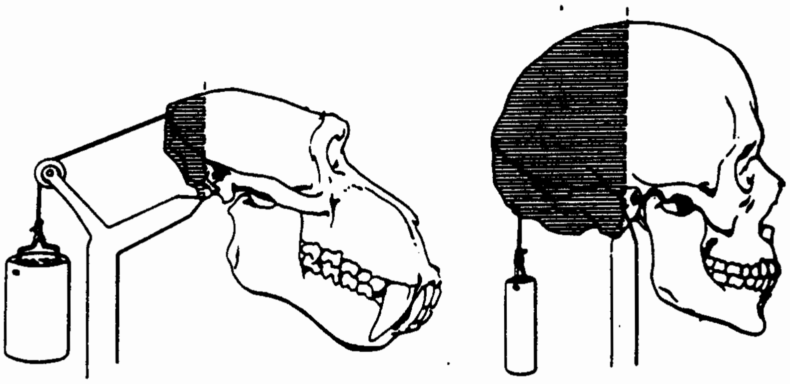

Figure 1.2 Skulls of baboon and man illustrating the difference in muscular bulk and strength required to hold the head on the vertebral column in such a position that the eyes would have been able to look straight in front. (From Tobias, 1982)

The spine : The vertebral column, particularly the lumbar region, became thickened and strengthened against compressive forces. In man, the sacrum is bent back abruptly and forms a promontory at the lumbar-sacral border. (Schultz, 1969) The cervical and lumbar areas of the spine curve convexly forward. These curves are maintained by ligaments and muscles, and in the case of the lumbar curvature, also by the wedge-shaped vertebrae. These curvatures are important for the absorption of the mechanical shock of walking - the spine acts as a springy column. In non-human primates, shock absorption is provided by flexible hands and feet and the springy lever action of a much longer and narrower ilium. (Schultz, 1969)

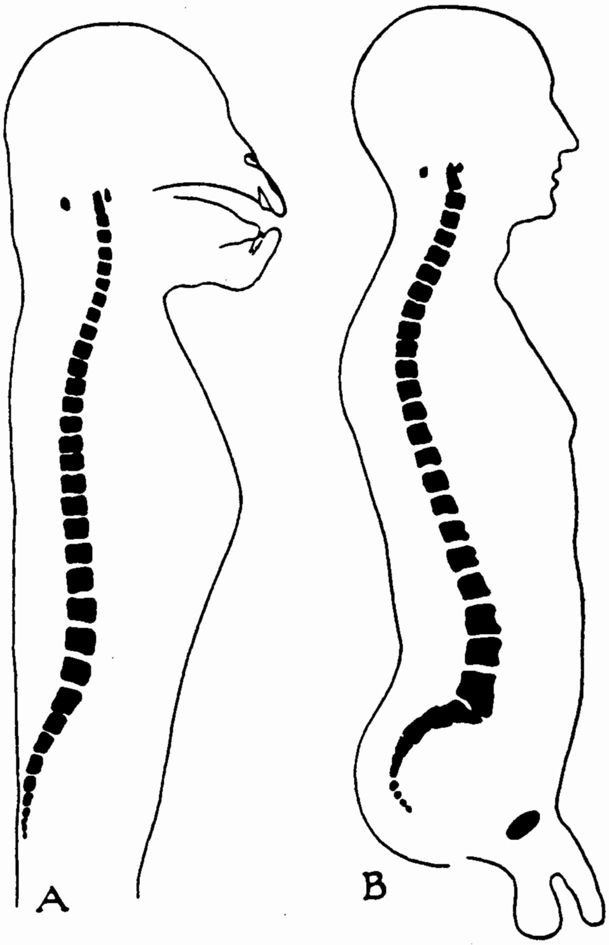

Figure 1.3 Median sagittal sections though the head and trunk of a chimpanzee (A) and of a man (B). Note the differences in spinal curvatures and also how, in upright man, the size of the vertebrae increase towards the lower lumbar vertebrae, as each vertebra supports a greater mass than the one above it) (From Tobias, 1982)

The thoracic cage : In man the thoracic part of the spinal column moved towards the centre of the chest so that the backbone became a more or less central column around which weight is distributed. This flatter thoracic cage placed the centre of gravity further back. (Schultz, 1969)

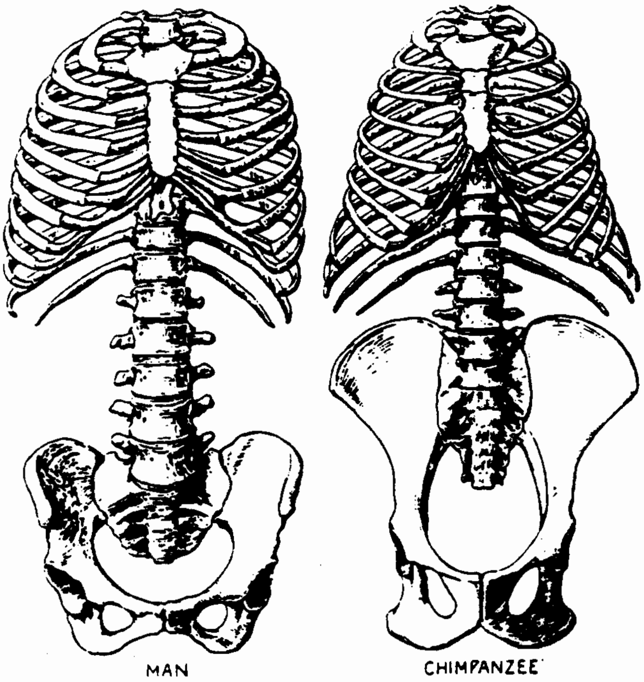

Figure 1.4 Front views of trunk skeletons of a man and a chimpanzee, reduced to same total length. (From Schultz, 1969)

The most marked differences between man and quadrupeds occur in the pelvis and lower limbs as all the body's weight is transmitted through these. When a quadruped attempts to stand erect, the hip must remain flexed because of the relatively long ischium. As a result of this and the weight of the long forelimbs, the centre of gravity shifts forward. To counteract this the knees must also be bent. The fully erect primate therefore needs a pelvis that is shortened and broadened.

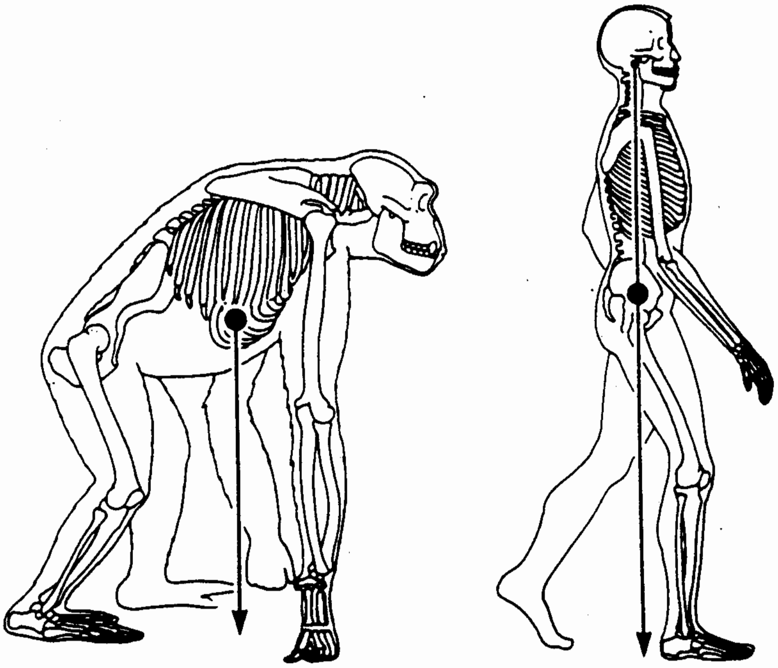

Figure 1.5 The weight-line of an ape in the oblique standing position falls between the fore-limbs and the hind-limbs. In upright standing and walking man, the axis of body mass passes from the occipital condyles of the cranial base, close to the vertebral column, through the hip joints to the feet. (From Tobias, 1982)

The pelvis : As weight from the upper body is carried through the lumbar-sacral joint, a better connection between the spinal column and the pelvis is needed. This connection is provided by the wider sacrum which wedges the hip bones apart and has a much larger area of contact with the hip bones (Schultz, 1969). The strength of the sacro-iliac joint is provided through sacrifice of almost all mobility. (Palastanga et al, 1989) The widening of the sacrum also allows for a larger birth canal which humans require as a result of foetal cranial enlargement. (Williams et al, 1989)

The ilia became shortened, broadened and tightly curved backwards and outwards. This shortening brought the auricular surfaces of the sacrum nearer to the acetabulum, the joint socket for the femoral head, so that the mass of the trunk could be transmitted more directly to the lower limb. The internal structure of the ilium also adapted to bipedalism. Areas that took more stress developed specialised cancellous bone structure. In addition to this, a prominent iliac pillar developed between the iliac crest and the acetabulum, helping to bear compression when the pelvis tilts during walking. (Tobias, 1982)

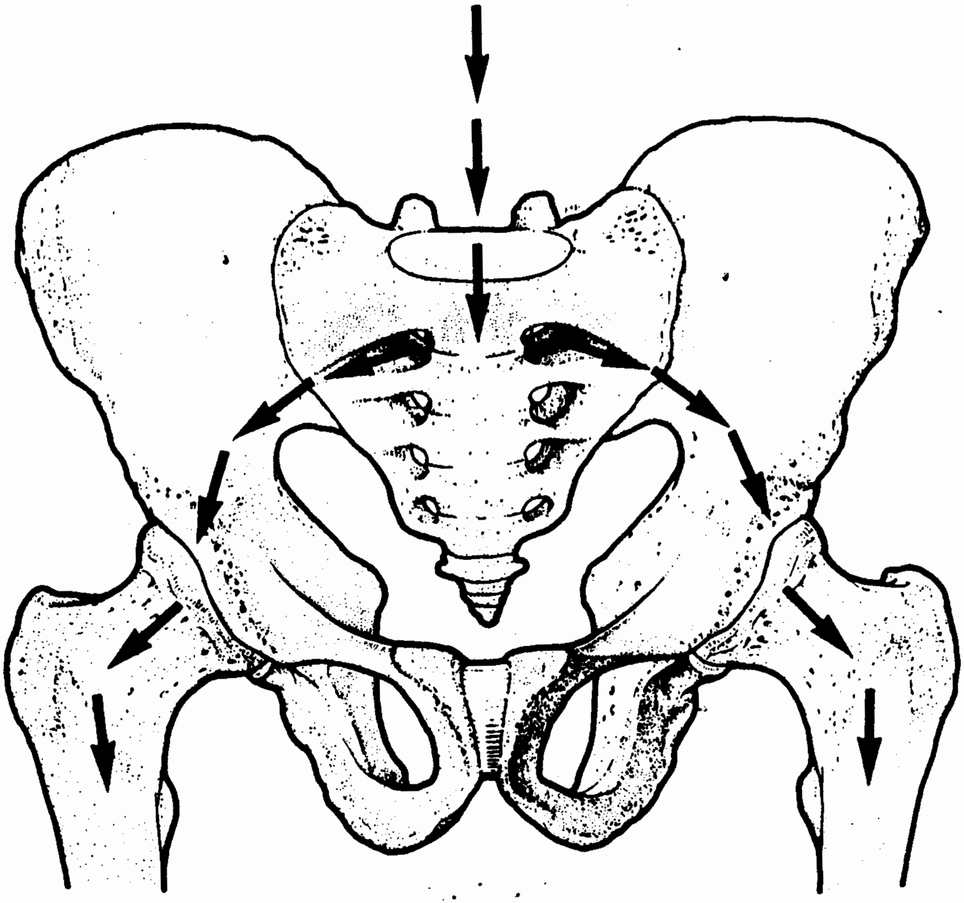

Figure 1.6 Transfer of weight from the vertebral column, through the pelvis to the femur. (From Palastanga et al, 1989)

The shortening of the ilia also prevents the pelvis from tilting forwards when body weight is transmitted to the hip joints. These changes to the pelvis have resulted in a shift in its positioning from an essentially horizontal to a vertical position. This means that the trunk can be held vertically but it has required a change in the orientation of the sacrum with respect to the ilium. As a result, the axis of the pelvic canal lies almost at right angles to the vertebral column.

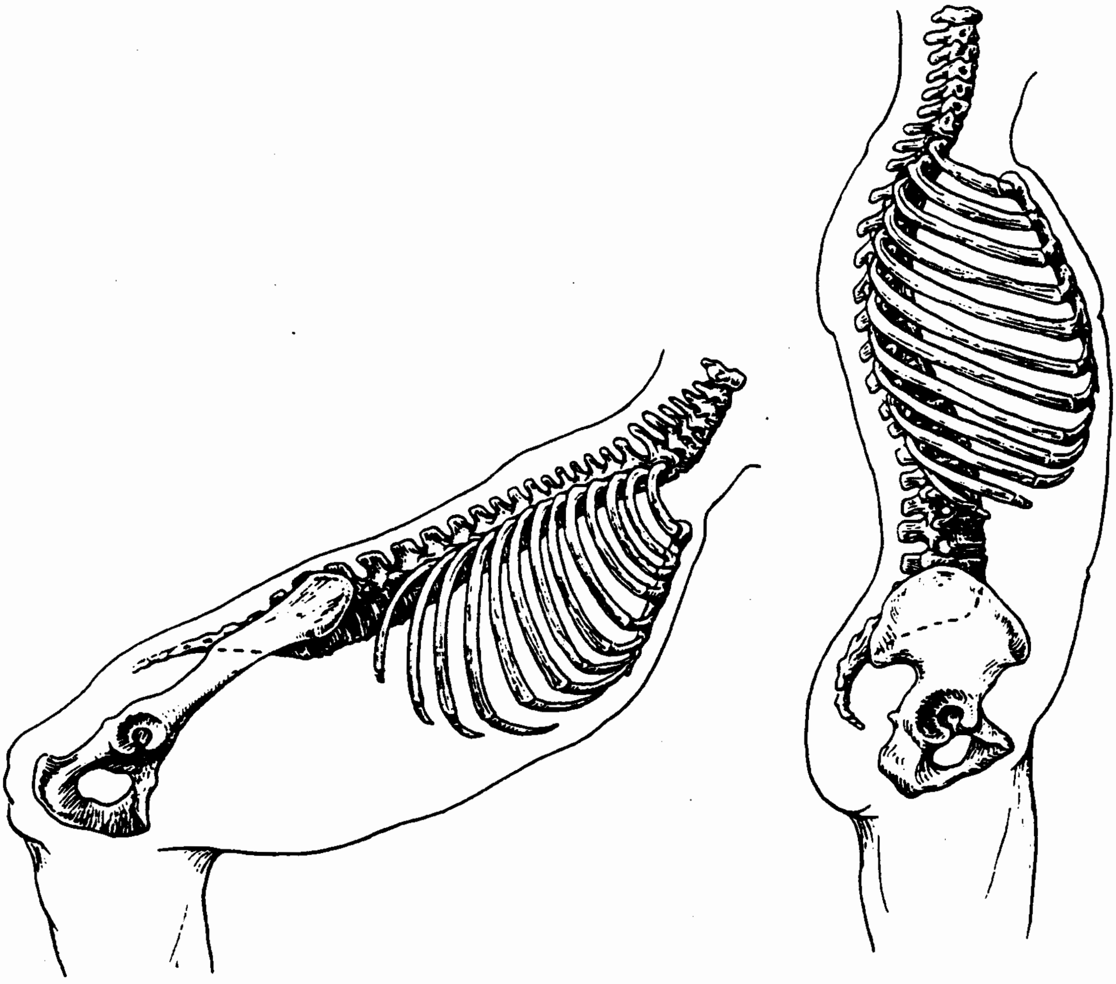

Figure 1.7 The curvature of the vertebral column and the relative size and position of the pelvis in adults of ape and man. (From Schultz, 1969)

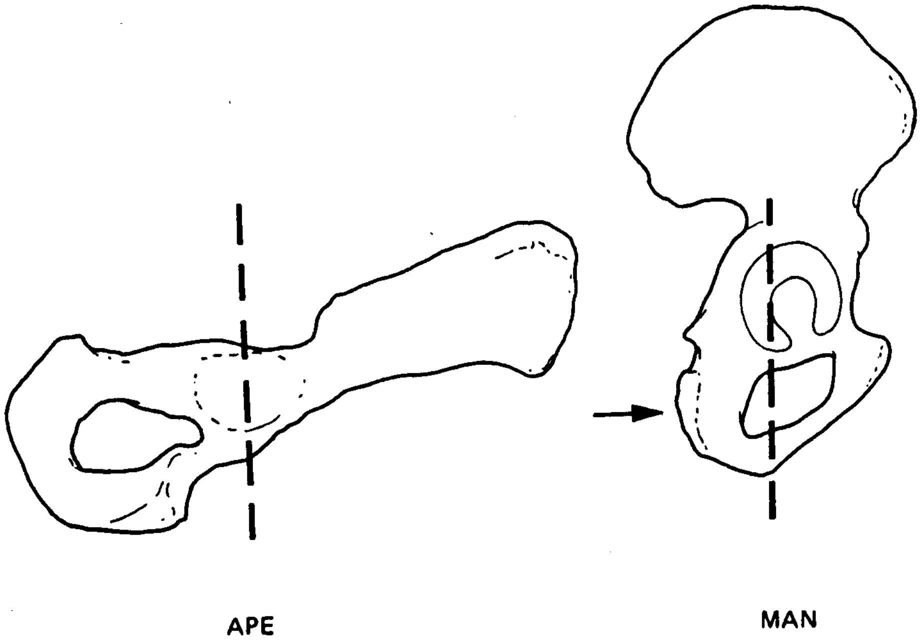

Figure 1.8 The evolutionary changes that have occurred to adapt the human pelvis for erect posture. (From Palastanga et al., 1989)

The femur : The head of the femur and the acetabulum became larger in man for more efficient weight transmission. The ischium is elongated in apes and shorter in man, while the femur is relatively short in apes and long in man. This results in two different leverage systems. In apes, with the long moment arm (the stable ischium) and the short lever arm (the mobile femur), the hamstring muscles act with power. In man, this situation is reversed and the power of action of the hamstrings is sacrificed for speed. (Tobias, 1982) (Palastanga et al, 1989)

Knees : The knees have been brought inwards toward the body midline as part of the pattern of centering body mass, reinforcing skeletal rather than muscular equilibrium. (Palastanga et al, 1989)

Feet : The foot has changed from a prehensile structure into a compact though flexible "plate" with parallel digits, from a grasping tactile organ to a locomotor prop. It has acquired a marked sagittal and transverse arch which contributes in a limited way to shock absorption. These arches become less curved in standing and walking. (Schultz, 1969) (Williams et al, 1989)

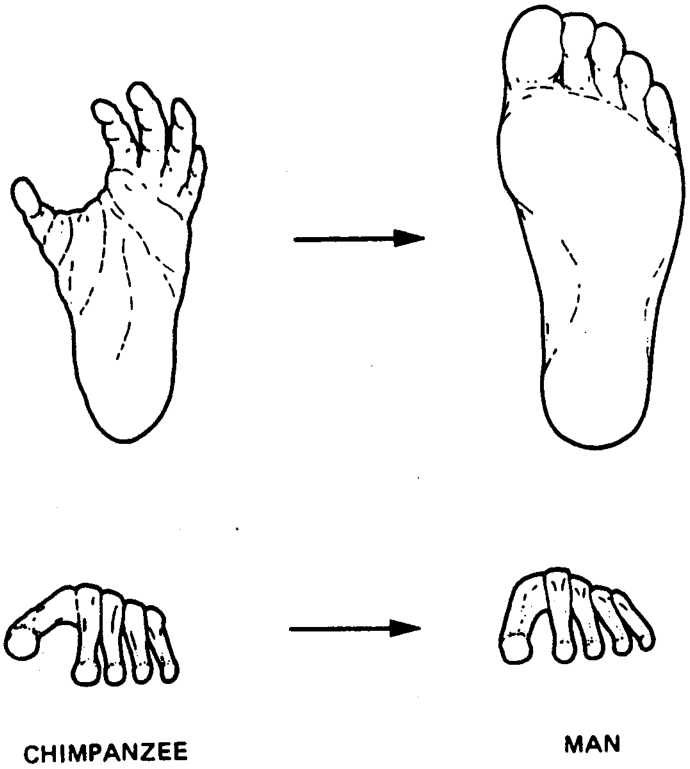

Figure 1.9 The evolutionary changes that have occurred within the foot during its adaptation to bipedalism. (From Palastanga et al , 1989)

Changes in musculature accompanied the above skeletal changes. The gluteus medius and the gluteus minimus changed from being the primary trunk extensors used for locomotion, to becoming hip abductors, involved in stabilising the pelvis during striding. Gluteus maximus, which is weakly developed in monkeys and apes, has enlarged in man as its attachment area, the posterior part of the iliac blade, has broadened and moved backwards. It has become powerfully developed and has its chief function in preventing the trunk from jack-knifing forward onto the legs.

Robinson (1972) maintains that there are two major requirements for efficient erect bipedal posture: the capacity to balance the body and the capacity to move the legs quickly. Widening of the iliac blades put the muscles attached to them in a better position to control lateral balance. Posterior-anterior balance was achieved by the spinal muscles working with the abdominals. The capacity to move the legs quickly is increased by man's powerfully developed gluteus maximus which gives the hip joint more play.

Having addressed the questions of why we are bipedal and the major anatomical adaptations undergone to achieve habitual bipedalism, it is necessary to consider in greater detail exactly **how** we stand - having achieved erect posture, how do we maintain it?

1.2 Upright man versus gravity

Pheasant defines posture as the relative orientation of the parts of the body in space. When a particular postural orientation is maintained over a period of time, the muscles are used to counteract any external forces acting on the body - the most ubiquitous being gravity. (Pheasant, 1986) During normal standing, the centre of gravity of the whole body mass plumbs to a point on the ground which is a few centimetres in front of the transverse ankle axis. (Hellebrandt and Franseen, 1943; Woodhull, et al. 1985)

In theory, a biped could stand if the leg and spine joints were ankylosed and the body was shaped so that the centre of gravity was exactly midway between its two feet. However, this would be very unstable and the slightest push would make it fall. In reality the centre of gravity moves according to the shape and position of the body. It can even be outside the body. The body is balanced when the resultant of all the forces acting on it is zero. (Roaf, 1977) This occurs when there is an overall balance of forces between the body and its surroundings and between parts of the body. (Grieve and Pheasant, 1982)

Good posture has been defined in this way: "the alignment which permits the musculo-skeletal system to function most efficiently, when standing, is one in which the body segments are superimposed on each other in a vertical column so that the weight is centred at the gravitational line which in turn passes through the centre of the base of support". (Winters, 1962 in Fox and Jones, 1967) This was referred to by nineteenth century German anatomists as "die normal Stellung" .

The column of bones carrying the weight to the ground can be thought of as a series of links stacked so that the line of gravity passes directly through the centre of each joint between links. Erect standing posture is determined by the relative arrangement of the body's link segments. (Dempster, 1955) The centres of gravity of these links and the movement centres of the joints cannot coincide perfectly with the common line of gravity and so complete passive equilibrium is impossible. External and internal counterforces which neutralise the forces of gravity are necessary to maintain this position. (Basmajian, 1985) Grieve and Pheasant (1982) suggested that as people can never stand completely still, posture should rather be thought of as a mean over a period of time.

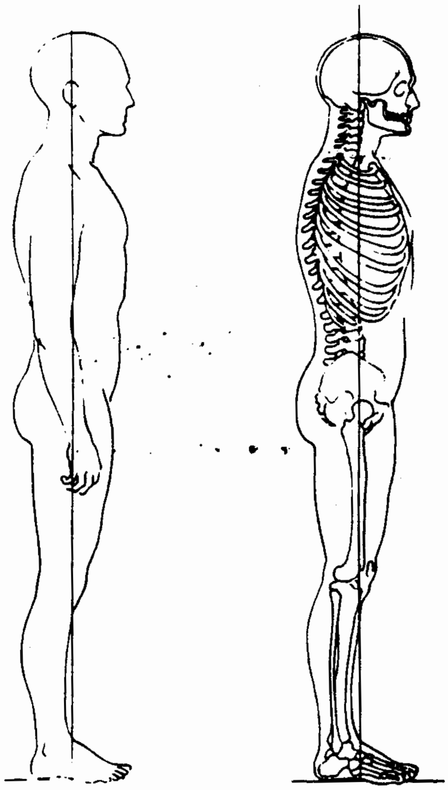

Figure 1.10 Line of gravity in normal erect posture. (From Basmajian, 1985)

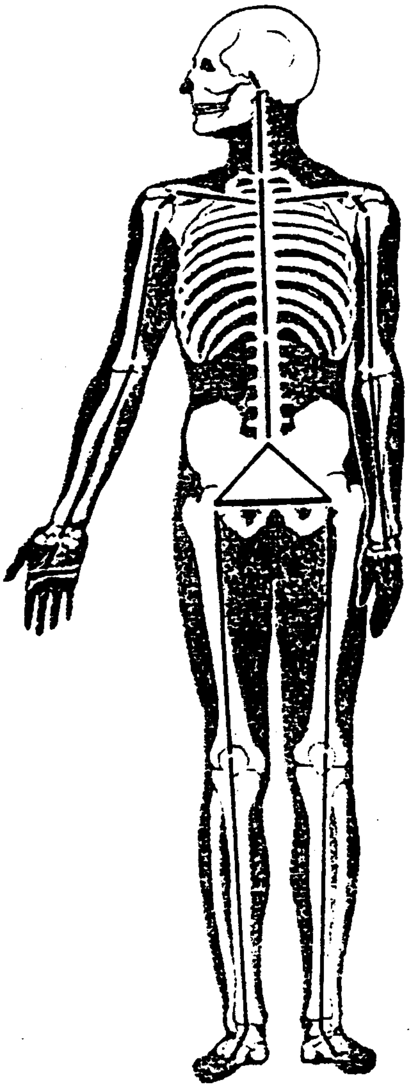

Figure 1.11. Plan of body links. (From Dempster, 1955)

"Normal" or "ideal" posture is defined as having the line of gravity of superincumbent body parts dropping in the midline between the following bilateral points: the mastoid processes, a point just in front of the shoulder joints, the hip joints (or just behind), just in front of the knee joints and just in front of the ankle joints. (Basmajian, 1985) Basmajian points out that once the upright posture has been attained, man has the most economical antigravity mechanisms of all mammals.

1.3 Muscle activity

When the body is pulled out of the line of gravity, muscular activity is required to bring it back into line. The anti-gravity muscles are :

a) the erector-spinae muscles : These act as the major extensor of the trunk but are also important in controlling trunk flexion. In trunk flexion and extension with straight knees, the activity of the erector-spinae muscles decrease suddenly when flexion of the trunk increases and relaxation of the muscles occurs in the fully bent posture. In the case of extension of the trunk, the pattern of activity is reversed. (Floyd and Silver, 1955) This decrease of muscle activity occurs when the flexibility of the lumbar vertebrae is limited (in flexion) and the increase (in extension) occurs when they recover their flexibility. (Tanii and Masuda, 1985) However, only very slight and sometimes intermittent activity is found in these muscles during relaxed standing. (Floyd and Silver, 1955) (Portnoy and Morin, 1956) (Basmajian, 1985)

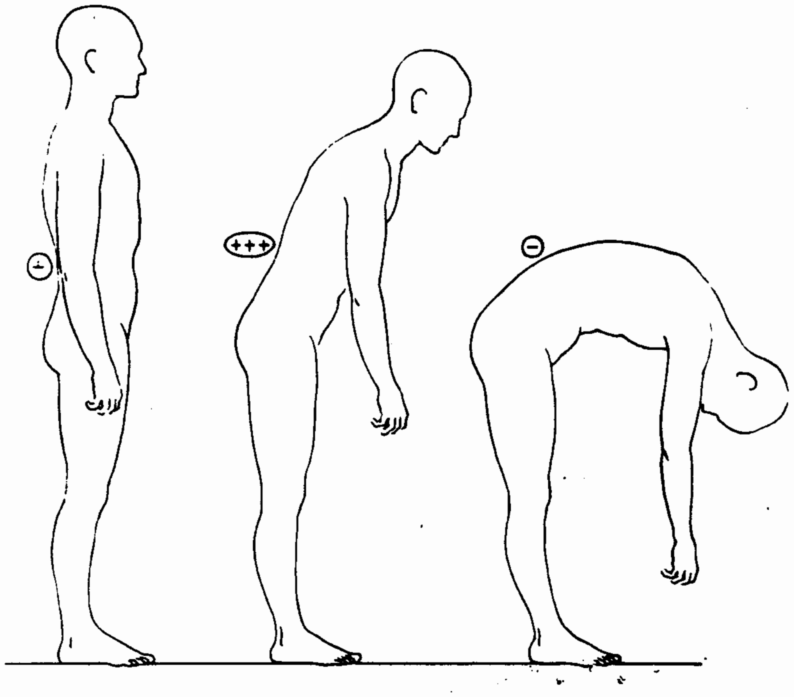

Figure 1.12. Diagram of activity in erector spinae during forward bending. (From Basmajian, 1985)

b) the leg muscles : Joseph and Nightingale (1956) concluded that the soleus of all people and the gastrocnemius of some people is active when standing at ease. They found that tibialis anterior was not active. They concluded that this was because the line of gravity falls in front of the ankle joint, necessitating activity in the gastrocnemius and soleus. Basmajian and Bentzon (1954) had a wide range of findings for all these muscles but, in general, found the posterior more active than the anterior. They also found that, in men, the gastrocnemius was more active than the other leg muscles whereas, in women, all the muscles examined showed similar degrees of activity. Smith (1954) also noted activity in the posterior crural group of muscles and suggested that this activity was concerned with anterior-posterior swaying of the body. Portnoy and Morin (1956) had similar findings and showed that the activity of the gastrocnemius increased when leaning forward.

c) the abdominal muscles : Zacharkow (1988) maintains that the abdominals play a role in upright standing by compressing and supporting the viscera and keeping the proper axial relationship between the thorax and the pelvis. The upwards force exerted on the diaphragm by the abdominals is thought to help keep the spine straight. (Roaf, 1977) (Kapandji, 1970) Floyd and Silver (1950) report, however, that activity in the abdominals during relaxed standing was only slight.

d) the intercostals : These muscles are important to posture because if rib posture fails, for example due to quadraplegia, the abdominals act asymmetrically on the spine causing scoliosis. (Roaf, 1977)

e) the hamstrings and gluteus maximus: These are primarily hip extensors. Gluteus maximus is the muscle mainly responsible for the erect position and, with the hamstrings, provides the main control in forward bending of the body at the hip joint. (Palastanga et al, 1989) Portnoy and Morin (1956) found slight activity in the hamstrings during normal relaxed standing. This was continuous in 50% of subjects and intermittent in the other 50% and increased on leaning forward.

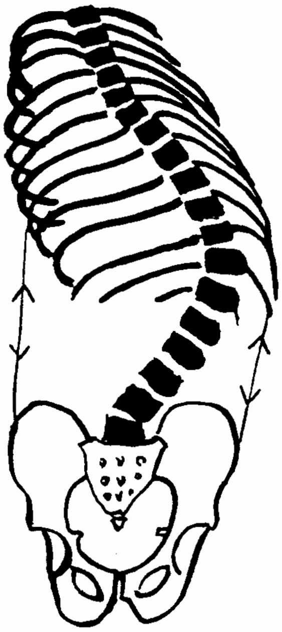

Figure 1.13. Asymmetrical action of trunk muscles in failure of rib posture. The turning movement exerted by the abdominal muscles is less on the convex side. (From Roaf, 1977)

f) abductors and adductors : When standing on both feet with the pelvis supported underneath on both sides, the ipsi- and contralateral adductors and abductors (gluteus minimus, gluteus medius and the tensor fascia latae) provide transverse stability. (Kapandji, 1970) According to Williams et al (1989), the activity of the adductors during symmetrical easy standing is minimal. When standing on one foot, the weight of the body tends to tilt the pelvis at the supporting hip so that stability is provided only by the ipsilateral abductors. (Kapandji, 1970)

g) iliopsoas : The psoas major and the iliacus are femoral flexors. (Williams et al, 1989) The iliopsoas was found to be constantly active during normal standing as it prevents hyperextension of the hip joint. (Basmajian, 1958) (Woodhull et al, 1985) This muscle keeps the pelvis tilted forward and so accentuates the lumbar lordosis. This forward tilting is counterbalanced by the hip extensors, the hamstrings and gluteus maximus. If the iliopsoas becomes hypertonic, the lumbar lordosis is increased. If these muscles weaken, the lumbar lordosis is flattened. (Kapandji, 1970)

h) the intrinsic muscles of the foot : The arch of the foot persists even when weight is supported. However, according to Basmajian and Bentzon (1954) the intrinsic muscles of the foot play no active role in the normal static support of the long arches of the foot during standing.

In general, it can be concluded that the standing posture, reflexly maintained, depends largely on the tonic support of the posterior muscles of the trunk and legs. The abdominals are only recruited when the person leans backwards or the lumbar curvature is consciously flattened. The forward bias is counterbalanced by the gastrocnemius, the soleus, the hamstrings, the spinal and neck extensor muscles. (Kapandji, 1970) These, then, are the main postural muscles which enable humans to adopt the upright stance.

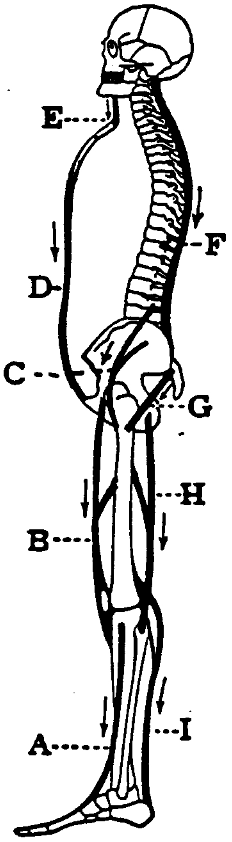

Figure 1.14. Antagonistic muscle groups responsible for erect posture. *A - Tibialis anterior, B - Quadriceps femoris, C - Iliopsoas, D - Abdominals, E - Neck flexors, F - Spinal extensors, G - Gluteus maximus, H - Hamstrings, I - Soleus gastrocnemius.*

1.4 Postural control

Musculo-skeletal adjustments to uprightness had the effect of bringing the line of weight transmission very close to an axis in a plane more or less equidistant from the dorsal and ventral surfaces of the body. (Tobias, 1982) However, the upright posture would still be a precariously balanced state without an adequate postural control system.

Barlow (1990) suggests the phrase "postural homeostasis" to describe the steady state in which the body keeps itself balanced. Work is done to maintain balance around a central "point of stillness" which is not fixed.

The postural control system has to perform three functions: support, stabilisation and balance. Appropriate contraction of the anti-gravity muscles provides support. Stabilisation of supporting portions of the body is particularly important during movement. Adequate balance ensures that when the body is stationary, the vertical projection of the centre of gravity falls within the supporting base. Compensatory muscle activity is required to counterbalance the continuously moving gravitational moments about the joints (Boman and Jalavisto, 1953). Grieve and Pheasant (1982) provide a very good model of the control of human balance in which intermittent ballistic corrections of alignment occur so as to keep the centre of foot pressure well within the base of support.

Although it is not known which centres in the central nervous system perform these functions (Rothwell, 1994), it is known that in order to support, stabilise and balance the body, the postural control system needs information about the relative position of the body parts and about any external forces which might be acting on the body (e.g. gravity). This information is provided by three classes of receptor - somatosensory, visual and vestibular.

All three classes of input contribute to stabilisation of the body during quiet stance. It is impossible to stand unassisted if all of these inputs are removed.

However, it has been shown that balance is possible with only one source of input (Rothwell, 1994).

In 1910, Sherrington stated that the act of standing in man is purely reflex (Kelton and Wright, 1949). However, Kelton and Wright (1949) argued that the reflex could not be a simple stretch reflex as it occurs with much less stretch than would be normally required. Today the postural reflex is distinguished from the simple stretch reflex. (Rothwell, 1994)

Movement of the centre of gravity which threatens balance or stability, is detected by the three classes of receptors and opposed by postural reflexes, the contraction of the appropriate postural muscles. These reflexes can be considered to be different to the simple stretch reflex in that the responses elicited by any one of the three sensory inputs can be modulated by the other inputs (Rothwell, 1994). Voluntary movement which anticipates postural displacement also serves to balance and stabilise the body and in some instances can occur even before the postural reflex is elicited (Rothwell, 1994).

The work of Collins and de Luca (1993; 1995) is based on the assumption that the act of maintaining erect posture can be seen as a stochastic process, i.e. characterised by a sequence of random variables. Based on their investigations, they conclude that two distinctly different neuro-muscular mechanisms are operating during quiet standing; a short -term open loop mechanism and a long-term closed loop feedback mechanism. The latter corresponds to the postural control system that receives information from visual, vestibular and somatosensory systems while the former uses open-loop control schemes which result in descending commands to muscles involved in postural control.

1.5 Postural sway

The body is in continuous motion even when a conscious attempt is made to stand still. This was demonstrated as early as 1862 by Vierordt (Thomas and

Whitney, 1959). Standing has been called “movement upon a stationary base”. (Hellebrandt, 1938)

Standing is characterised by imperceptible anterior-posterior and lateral sway as the centre of gravity shifts incessantly. (Hellebrandt, 1938) (Hellebrandt and Franseen, 1943) (Murray and Peterson, 1973) The magnitude of antero-posterior sway has been shown to be greater than that of lateral sway. (Hellebrandt, 1938) (Boman and Jalavisto, 1953)

Muscle activity in the leg related to antero-posterior sway was found to be periodic. (Basmajian and Bentzon, 1954) This periodicity was first noted by Floyd and Silver (1950) and commented on by others. (Hellebrandt,1938; Smith, 1957) Thomas and Whitney (1959) found high frequency oscillations associated with heartbeat and muscle tremor (8 - 12Hz) and low frequency changes in the centre of foot pressure (less than 0,4Hz).

Early studies of postural sway assumed that the body stayed rigid above the ankle joints. (Hellebrandt, 1938; Smith, 1957) Thomas and Whitney (1959) found that there was no rigidity between the trunk and the lower limbs during standing. They also found that postural activity was cyclical in nature although cycles were irregular in duration and amplitude. Changes of trunk inclination were usually synchronised with movements of the centre of foot pressure. The trunk was found to rotate relative to the hips during standing with the axis approximately through the hip joints. (Thomas and Whitney, 1959)

The concepts of centre of foot pressure (CFP), effective foot base (EFB) and “underprop diameter” are closely linked to an understanding of postural sway. The evolution of bipedalism has been marked by a narrowing of upright man’s base of support and the elevation of the body’s centre of gravity. This design is not conducive to stability as the body’s centre of gravity is placed high above a relatively small supporting base. (Hellebrandt and Franseen, 1943)

The EFB or "underprop diameter" gives an indication of the distribution of pressure under the foot, or more basically, under the supporting area or the stabilising base. Morton (1952, in Thomas and Whitney, 1959) considered the EFB to extend from the heel margin to the heads of the metatarsals and that, when standing, the line of gravity falls midway between the two margins. Hellebrandt (1938) concluded that 40% of the underprop diameter lay posterior to the gravity line. She recorded the movements of the CFP on the ground, with the implication that these movements were directly related to movements of the vertical projection of the centre of gravity of the whole body.

These researchers assumed that the CFP coincided with the vertical projection of the centre of gravity of the body weight. Based on his research into the events of postural sway, Whitney (1962) argued that this assumption could not be made even for minimal postural sway. A study of force-motion relationships in common human activities like sitting down and standing up, has shown that during dynamic activities the line of gravity and the CFP are two distinctly different although highly related entities. (Murray et al, 1967)

Whitney (1962) defined the EFB as the distance between the antero-posterior limits of the CFP and through his research found the EFB to be about two-thirds of the length of the foot. He suggested that the EFB provides a quantitative estimate of the body's functional ability to resist postural disturbance imposed by external forces. He concluded that when the CFP falls anterior to the ankle axis, the chief muscle activity is for plantar flexion and so involves the soleus and the gastrocnemius. When the CFP falls posterior to the ankle axis (as he found in heeling and toeing and repeated swaying) the tibialis anterior and toe extensor muscles are active.

Cavanagh et al. (1987) showed through load distribution analysis that the heel carries 60% of the weight bearing load, the midfoot 8% and the forefoot 28%. The toes were found to be minimally involved in weight-bearing.

Postural sway has been found to increase with age, especially after the age of 80. (Boman and Jalavisto, 1953) Collins and de Luca (1995) found that healthy ageing is associated with significant changes in the dynamics of the postural control system. A study by Pyykko et al. (1990) found postural control to be reduced in subjects over 83 years old. They suggest that this is a result of deterioration in the function of stretch reflexes and in eyesight. The very elderly seem to rely on visual feedback for control of posture which is slower than proprioceptive feedback and therefore have more difficulty in reacting quickly to right posture.

Schieppati et al. (1994) found that the maximum extent of antero-posterior displacement of the centre of foot pressure (CFP) was significantly less in elderly subjects. Robbins et al. (1995) found that sensitivity to foot position declines with age, thus possibly contributing to the frequency of falls later in life.

Hellebrandt and Braun (1939) however, found no significant difference in postural sway based on age or sex. Similarly, Fernie et al. (1982) and Dornan et al. (1978) found no age-related differences in postural sway.

Jeong (1991) showed that both respiration and eye condition affect the sway distance of the CFP. The sway distance was greater when subjects were holding their breath after inspiration than when they were holding their breath after expiration. In addition, rate of sway was increased by increasing respiration rate. In a study that compared the CFP (centre of foot pressure) of sitting and standing subjects during quiet breathing, deep breathing and apnoea, Bouisset and Duchene (1994) concluded that respiration is a significant input for postural control.

Holbein and Redfern (1993) investigated the effects of various load magnitudes for their effects on postural stability. They found that heavier loads resulted in greater sway magnitudes and slower sway velocities than unladen standing.

Excessive sway was suggested by Eysenck (1947) to be one of the best indications of conflict in one's personality. He showed that neurotic people display larger swaying oscillations than normal people. This may be linked to the possibility that postural control centres are distributed in many separate regions in the central nervous system. (Rothwell, 1994)

1.6 Upright man versus himself

Having achieved uprightness and overcome gravity through musculo-skeletal and neurological adaptations, the quality of man's uprightness is nevertheless partly determined by emotional and cultural influences. Nineteenth century anatomists assigned varying importance to the upright posture. Some thought there was something divine in being upright, "that majestic attitude which announces man's superiority over all inhabitants of the globe" (quoted in Barlow, 1990, source not given). In the first quarter of this century it was still thought that we and our spines were perfectly fashioned and that the world we lived in was to blame for any problem.

As the field of orthopaedics began to grow, it became clear that it was not necessarily man's environment that was at fault but his imperfect adaptation to it. Scientists began to see man as a "made-over" animal. (Hooton, 1936)

Dystonia is the medical name for faulty muscular tension patterns. Dystonic postures are most obvious in the postures we develop when keeping still, resting or repeating actions in the course of daily life - at home or at work. Culture and training have much to do with the static postures that we adopt. Hewes (1957) wrote that over 1,000 comfortable resting body positions have been listed world-wide - all of them variations of sitting, lying, standing or kneeling. This wide variety is the result of cultural diversity.

Fahrni (1966) points out that many people have been taught that it is manly to stand for long periods and that it is a sign of strength and stamina, e.g. soldiers. The military "attention" position has been impressed on many children as the ideal way to stand with almost all the voluntary muscles tensed. The curves of the spine are exaggerated and the shoulders thrown back. We have been told that to "slump" is bad and so we conclude that it is bad for our backs.

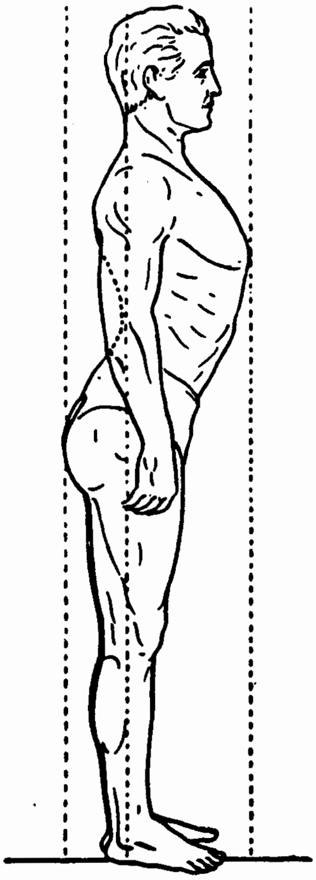

Figure 1.15. Exaggerated standing posture, "at attention". (From Zacharkow, 1988)

Fahrni describes the Bhil tribe in India whose culture does not include any postural instruction. Their postural habits are "free and unencumbered". Standing still is only done for a few minutes each day - If two people meet and wish to chat, they immediately squat. The symptoms of back pain and strain are apparently completely absent in this society. (Fahrni, 1966)

In other cultures, people maintain the upright position for long periods with the aid of sticks, chin supports and meditation bands. Nilotic man presents an interesting example because, standing on one leg, the weight of his arm on his flexed leg causes pressure to force his supporting leg into full extension thus locking the knee - so he is able to hold himself upright with minimal muscular activity. (Roaf, 1977) (See drawing on page ii, after Title page)

Barlow (1990) maintains that by the age of about thirty months, infants have already adopted the mood of their families (or dominant parent) and their associated postures. This continues all our lives, as we imitate the attitudes of those we admire in order to make contact easier. This "posture swapping" occurs in both directions although it tends to favour the dominant person.

In Western society, good posture has many different meanings to different people, e.g. the model throws her pelvis forward to show off her clothes (hyperextension of the hip joints during gait); the beauty queen arches her back and pushes out her bosom (hyperextension of the lumbar spine and anterior tilting of the pelvis); the shop assistant and the bar-fly relax with the weight on one leg. (Rasch and Burke, 1967) These attitudes become fixed patterns affecting body functioning. While they may become the most convenient attitudes for individuals to assume, they are not always the most biologically appropriate.

Barlow (1990), a physician and a teacher of the Alexander technique, points out that there is, for any given situation, a way of using the body which makes for the least wear, tear and fatigue, and the best functioning. The idea of ease and economy of effort is not new. Herbert Spencer in his "Essays" wrote of "movements which are affected with economy of force and postures which are maintained within this economy". Marcus Aurelius wrote that "the body ought to be stable and free from all irregularity whether in rest or in motion".

1.7 The importance of foot position

Mosher (1913, 1914, 1919 in Zacharkow, 1988) stressed that proper posture is largely dependent on the position of the feet in standing. Although the meaning of "proper" posture is debatable, it is intuitively obvious that poor foot posture can throw the whole body out of balance. As soon as a child starts to stand, sensory impulses originate in the soles of the feet and these have an important effect on balance and posture. (Roaf, 1977) Zacharkow(1988) considers foot position, along with activation of the erector-spinae muscles, to be critical for correct pelvic alignment and stabilisation.

Foot position is closely linked to postural sway as the feet determine how stable a base is provided during standing. As early as 1900, Haycraft showed how the shape and size of the supporting area depends on the separation of the feet on the ground. (Haycraft, 1900 in Whitney, 1962) In addition, the supported structure is made stiffer as the feet are moved apart because more muscles are involved. If the structure is stiffer, then the amount of movement will decrease (Rothwell, 1994). Increasing the distance between the feet also results in additional stability because the body centre of gravity is lowered. (Glassow, 1932 in Zacharkow, 1988)

Morton (1935), an early authority on feet, advocated that the most "natural" position for the feet was with the heels together. Kirby et al (1987) tested the hypothesis that variations in foot position would significantly affect standing balance. They found that when the feet were together, the subjects exhibited more postural sway than when they moved their feet 15, 30 or 45cm apart. Moving one foot up to 30cm anterior or posterior increased sway. They also tested five variations in foot angle and found that the least sway occurred with the toes 25 degrees out and the most with the toes 45 degrees in. In addition, they found that the mean position of the centre of pressure was closest to the geometric centre of the base of support when the feet in the 25 degrees "toes out" position. They were able to conclude that foot position is a very important determinant of standing balance.

It is worth noting that, in subjects wearing shoes, heel height has been found to affect the degree to which "out-toeing" is comfortable. Kendall et al (1952) showed how various degrees of "out-toeing" corresponded to different heel heights and foot lengths. They found that stability is increased when the base is square rather than triangular. They also found that although "out-toeing" may increase lateral stability, it results in the loss (proportionally to the angle of separation of the front of the feet) of stability in the antero-posterior direction.

1.8 Postural stress and the physiology of standing

A sustained posture like standing, requires an overall balance of forces between the body and its surroundings and also between parts of the body. Gravity must be constantly opposed by muscular activity and/or passive tensions in the soft tissues. This type of muscle activity is referred to by physiologists as "static work". Grieve and Pheasant (1982) define postural stress as the mechanical loading imposed on the body by virtue of its posture. Postural strain is the sum of the body's various responses to this stress. Individuals respond to postural stress in vastly different ways depending on their fitness levels and factors as obscure as differences in the central nervous system. (Pheasant, 1986)

Standing in one place involves static effort due to prolonged immobility of the joints of the feet, knees and hips. However, very little of the resulting pain and discomfort results from increased muscular effort. If energy consumption when supine was taken to be 100% then standing upright would increase energy consumption by only 8 to 10%. (Grandjean, 1973) The pain and discomfort is mainly due to the stress placed on the ligaments and the skeletal system. (Basmajian, 1985) Even before the experimental demonstration of postural sway, Weber and Weber contended in 1836 that erect posture was maintained, not so much by muscular activity as by non-active ligamentous tension. (Thomas and Whitney, 1959)

Constrained standing which forces the line of gravity further from the axes of rotation of the weight-bearing joints, places a greater strain on the muscles. (Roaf, 1977) The same applies if the line of gravity does not fall within the area of support at foot level. For instance, when a person stands and leans forward from the waist, the postural loadings on the hip extensor or the back extensor muscles are proportional to the horizontal distance between the hip and the lumbro-sacral joints, respectively, and the centre of gravity of the upper part of the body. (Pheasant, 1986)

Zhang et al (1991) concluded that constrained standing affects body movement, perceived fatigue and, to a lesser extent, task performance. Corlett and Manenica (1980) maintained that, in the short term, postural strain can distract an operator, reduce output and increase the likelihood of errors. In the long term, they cite postural stress as a causative factor in chronic musculo-skeletal disorders.

If static postures are maintained repeatedly over a long period of time, this can lead to deterioration of the joints, ligaments and tendons. Observation shows that increased static load leads to increases in disc inflammation, tendon sheath inflammation, inflammation of the attachment points of tendons and symptoms of chronic degeneration of the joints in the form of arthritis. (Grandjean, 1980)

Intradiscal pressure increases when bending forward in a standing position. If intradiscal pressure in standing upright is taken to be 100% then the pressure when standing with a 20 degree forward inclination of the trunk is at least 50% more. (Nachemson, 1976) Over a long period, this can result in pathological degeneration of the discs which is the main reason for frequent backache. (Kersley, 1979 in Pheasant, 1991)

Body height decreases during the day by approximately 15mm (around 1% of total stature) and recovers when lying in bed at night. This is due to intradiscal fluid efflux (when upright) and influx (when supine). (Corlett and Eklund, 1986) Increased back load (e.g. the biomechanical load due to leaning forward when standing) can increase the rate of body-height loss by placing the discs under pressure and thus increasing the rate of intradiscal fluid efflux.

Being upright imposes a hydrostatic handicap which makes man vulnerable to peripheral circulatory collapse. (Hellebrandt and Franseen, 1943) Cavanagh et al (1987) found that peak plantar pressures during standing may be at least 137 kPa which exceed the normal peak systolic blood pressure values of 17 kPa. This results in occlusion of blood flow through the foot. Basmajian (1985) suggested that fatigue in the lower extremities after prolonged standing is more a result of venous and arterial circulatory insufficiencies and pressures on inert body structures than due to continuous muscular contractions.

Labropoulos et al. (1995) examined the incidence of venous reflux in surgeons who typically are exposed to prolonged standing work. They concluded that venous reflux was more frequently seen among symptom-free surgeons than a control group.

Ward et al (1966) found that standing resulted in a marked peripheral pooling of blood due to the influence of gravity. In addition, when comparing standing to the supine position, they found that the stroke volume during standing decreased 45%, heart rate increased 36% and cardiac output decreased 27%. Frey et al. (1994) confirmed that standing increases diastolic and mean arterial pressures, heart rate, total peripheral resistance and thoracic impedance while it decreases cardiac output, stroke volume and mean stroke ejection rate.

Shirreffs and Maughan (1994) found that subjects who were supine for an hour had higher whole body bioelectrical impedance, higher blood and plasma volumes and lower serum potassium concentrations than they did after standing for the same length of time.

Plasma and salivary concentrations of melatonin (which is used as a circadian marker rhythm) were found by Deacon and Arendt (1994) to increase when moving from a supine to a standing position. This can be explained by the decrease of plasma volume in standing.

Standing up from a supine position was found to increase the dimension of the nasal passages. (Kase et al. 1994) This may be linked to the cardiovascular changes which are associated with standing, e.g. increased heart rate.

1.9 Movement while standing

Although there is increased venous hydrostatic pressure during standing, the "venous muscle pump" can easily be activated by moving. It may even be activated with involuntary postural sway. (Hellebrandt et al, 1940)

Fidgeting is a defence against postural stress. It is usually subconscious as we fidget before we become consciously aware of discomfort. (Pheasant, 1986) The urge to move ('Bewegungsdrang') can be caused by ischaemia, temperature, humidity, boredom, general stress, 'dimensional misfit' (i.e. some discrepancy between environmental dimensions and linear anthropometric dimensions), the individual's daily rhythm or some other behavioural factor. (Branton, 1969; Pheasant, 1986)

Postural sway can be seen as the body's spontaneous attempts to attain relative stability of its segmented structure. (Branton, 1969) However, this doesn't account for the actual changes in posture which take place while standing, e.g. shifting the weight from foot to foot. This falls into the area between body mechanics and behaviour. Spontaneous behaviour has been found to regularly produce a variety of postures.

It may seem that this variety merely represents random changes in position due to ischaemia in areas of the foot but this does not explain why some positions are held longer than others. While "dimensional misfit" and ischaemia may account for changes in position, Branton (1969) argued that there is another kind of interaction that takes place between the person and his environment which accounts for the variety of postures. This is the result of a primitive and deeply ingrained skill acquired in childhood which largely determines posture maintenance throughout an individual's life.

Changing posture is not a simple matter of shifting a foot forward or up onto a footrest. As the body is essentially a system of links, skeletal, ligamentous and muscular systems attempt to maintain the body's link segment alignment with the least expenditure of energy. Changing the position of one segment of this chain leads to compensatory adjustments in adjacent links and so increases muscular expenditure. (Basmajian, 1985)

1.10 Asymmetry in standing

Standing may be symmetrical or asymmetrical. In symmetrical standing, the limbs and trunk are symmetrically disposed about the medial plane, each foot supporting approximately half the body weight. The lumbar column curves convex anteriorly. In asymmetrical standing, the body weight is supported almost entirely on one limb while the other assists in maintaining balance. The knee of the balancing limb is slightly flexed, the foot is antero-lateral to its partner. As a result, the pelvis is tilted laterally down on the resting side while the spinal column shows a curve in the lumbar region concave towards the supporting limb. To compensate for this lumbar lateral flexion, the thoracic column is flexed concave towards the resting limb and the cervical column is flexed concave towards the supporting limb. (Kapandji, 1970)

The asymmetrical standing attitude is used four times as often as the symmetrical position. (Smith, 1953) In 1862 Vierordt attached a pen to the head of a subject so that the pen left a trace on paper as the subject moved. He found the fewest oscillations with the asymmetrical position. (Thomas and Whitney, 1959) Marsk (1958) found that people working with the right hand tended to use the left foot as the supporting foot.

Hellebrandt et al (1943) postulated that this stance asymmetry in right-handed people is "compensatory for a right-sided morphological preponderance associated with anterodextral functional limb preference." They found that during relaxed standing, the vertical projection of the centre of gravity tends to fall slightly to the left and behind the supporting base.

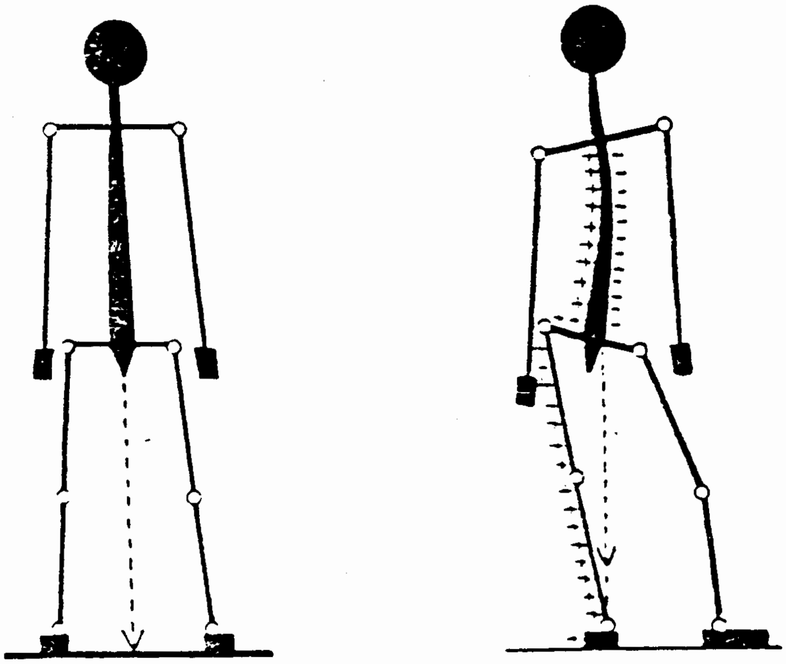

Figure 1.16. Diagrammetric representations of symmetrical and asymmetrical standing. The dotted line represents the line of the centre of gravity. (From Smith, 1953)

Kirby et al (1987) found that when the feet were together, there was a tendency to stand more on one foot. Murray and Peterson (1973) recorded the variability in weight distribution of forty normal men during comfortable, erect standing. Sixteen of them put more weight on their dominant side, eleven on their non-dominant side and the rest varied for different test periods. Weight shifting from foot to foot occurred incessantly for all subjects, with variable amplitudes and at random intervals.

Schoberth (1962 in Zacharkow, 1988) maintains that asymmetry is the result of striving for the most economic use of muscle power. However, early researchers stressed the importance of learning a different way to shift the body weight from side to side with prolonged standing. Mosher (1913, in Zacharkow, 1988) suggested placing one foot forward and swaying gently forward until the weight rests on the ball of the forward foot. Lee and Wagner (1949, also in Zacharkow,

1988) stressed that one should never stand with the weight on one foot unless it is a "one-foot-forward" position and with the weight on the forward foot.

This forward weight shifting is thought to prevent spinal stress and the loss of body symmetry from common asymmetrical standing postures and can be used at the workbench. (Zacharkow, 1988) Sparger (1960), in a book on anatomy and ballet, suggests that repeated asymmetrical side-stepping induces heavy lateral bending moments on the spine. Asymmetrical forward stepping must then be assumed to avoid this problem.

Rys and Konz (1989) tested the effect of the "one-foot-forward" position on comfort, foot volume, heart rate, and foot and calf temperature. Forward standing was found to be experienced as more comfortable in all areas except the thigh, leg and forefoot (as opposed to the heel). They found no significant differences for any of the other variables except instep temperature which was higher for "forward" standing than "normal" standing. These researchers also found that prolonged standing increased the "footprint area", i.e. the area in contact with the floor.

Kendall et al. (1952) sought an explanation for the phenomenon that the symptoms of chronic sciatica, associated with tight lower back muscles, increased lordosis, rotation and unilateral pelvic tilt, occurred more on the right than on the left side. They maintained that patterns of faulty body mechanics bear a close relationship to handedness.

1.11 Standing and working

Corlett and Manenica (1980) defined industrial work as "the achievement of a desired performance by a combination of energy expenditure, information handling and the adoption of positions appropriate for the first two activities". The area that gets the least attention, in their view, is working posture - even though the physical component in most jobs is postural and not high energy expenditure. The postural component is so intrinsic that it tends to go unrecognised.

van Wely (1970) showed that there is a high correlation between specific "bad" postures at work and specific sites of pain or symptoms of musculo-skeletal diseases. In particular, standing (especially with a pigeon-footed stance) was found to have a high probability of resulting in pain or other symptoms in the feet or lumbar region. Leaning forwards while standing was also found to affect the lumbar region and the erector-spinae muscles.

Tang et al. (1995) conducted a survey of 965 workers and concluded that the main factors affecting the prevalence of low-back disorders were workload and working posture. An investigation by Chavalitsakulchai and Shahnavaz (1993) involving 1000 workers confirms that poor working posture and prolonged standing are two of the main factors associated with musculoskeletal discomforts.

Standing workers who are characterised by low energy expenditure and constrained working conditions, suffer as a result of the adoption of persistent postures. A posture adopted to perform a particular activity may first become habitual and finally irreversible.

For example, sustained forward inclination of the trunk requires sustained activity in the erector spinae muscles. The tension in these muscles results in an equal and opposite compression in the spinal column. Subsequently, an occupation requiring prolonged forward leaning while standing carries with it the risk of disc degeneration. Some occupational groups, lathe operators, bricklayers, dentists and draughtsmen, to mention just a few, have a tendency to develop spinal deformities associated with the positions in which they work. The connection between deformities and occupation was remarked on as early as 1713 (Ramazzani, 1713 in Pheasant, 1986) although it has received very little scientific investigation.

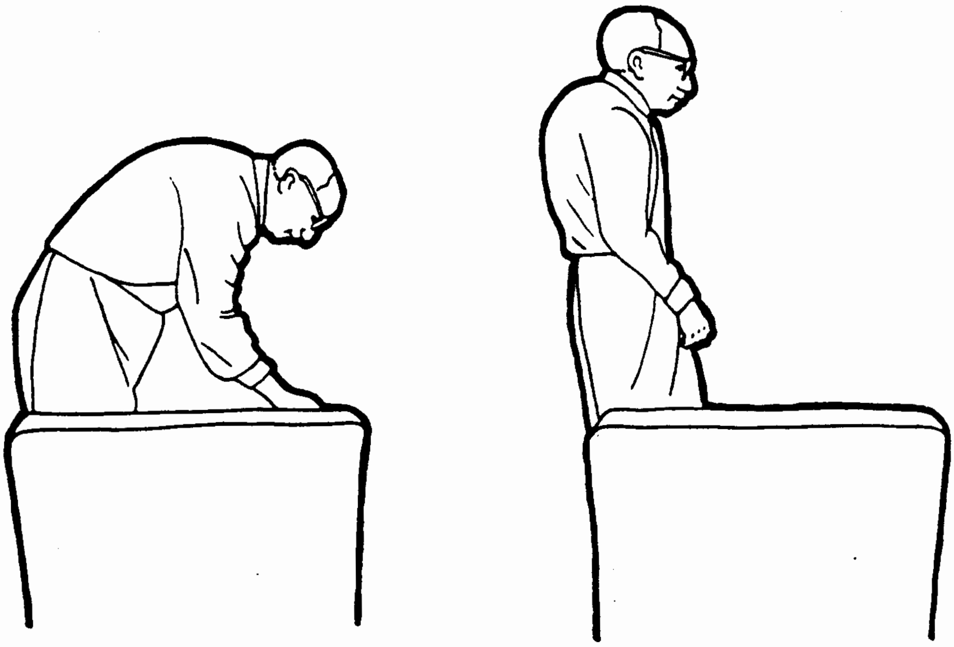

Figure 1.17. (From Pheasant, 1991) The upholsterer : left - working position; right - standing position.

Fox and Jones (1967) observed common working postures in dentists. Dentists (at that time) stood for hours in a confined "envelope" and the postures they adopted had to provide the stability to enable them to do fine specialised work. Fox and Jones found that the dentists tended to bend forward from the lumbar region, using the pelvis as if it was part of the legs. They also tended to retract the head backwards and downwards. This action leads to compensating kyphosis in the thoracic spine.

Tasks requiring prolonged standing in which people work in constrained areas are common in industry and daily living. However, the current literature contains very little in the way of research and recommendations for standing workers when compared to that published for seated workers and for workers engaged in manual handling of loads.

Various researchers have reported on the use of different kinds of floor coverings to prevent fatigue during standing, for example : (Rys and Konz, 1994) (Stuart-Buttle et al. 1993).

Grandjean et al. (1968) studied the working postures of 24 saleswomen who stood in one place for over five hours a day and were exposed to considerable static strain as a result. The researchers used a questionnaire to ascertain what the bodily aches and pains of workers were. They concluded that prolonged standing in one place is the common cause of ailments affecting the legs and feet of saleswomen.

Buckle et al. (1986) found that among women working in department stores, prolonged standing was frequently associated with back pain. They also found that among women working in supermarkets in cramped work stations, pain and discomfort in the hips, legs and knees could be attributed to prolonged standing. In general, those workers reporting back pain spent less time walking at work and had to perform more twisting and reaching movements. Those reporting pain in the feet spent more time standing, walking and kneeling. They concluded that there was a clear relationship between the prevalence of foot pain or discomfort and the proportion of the working day spent on the feet.

Magora (1972) found that people who stand continuously at work have a high prevalence of back pain. Those workers who are free to vary their posture and stand or sit at will have a low prevalence. Somewhat counterintuitively, his findings showed that people who stood regularly for less than four hours had a higher prevalence than people who stood regularly for more than four hours.

The work of Rys and Konz (1994) has provided useful data on various aspects of standing which may be used as a starting point to develop recommendations for standing work. DeLaura and Konz (1990) reported that, when standing at a workstation, space is required for the toes under the machine or bench which is at least 150mm deep, 150mm high and 500mm wide.

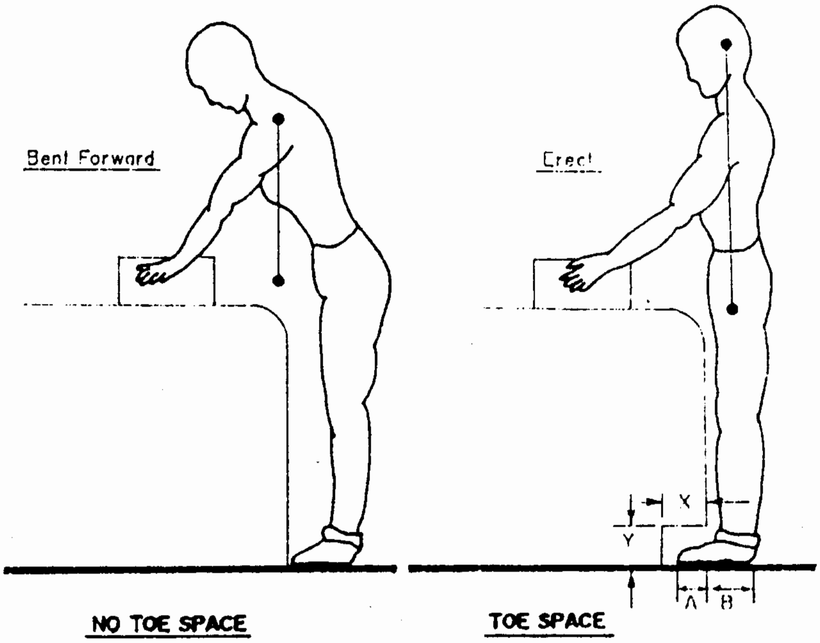

Figure 1.18. Person with no foot clearance space (left) and person with adequate foot clearance space (right). (From Rys and Konz, 1994)

McCormick and Sanders (1982) recommend that standing workers should be able to alternate their postures and they suggest work-surface heights which are based on the nature of the tasks to be performed. Grandjean (1980) recommends that the working height be adjusted to suit the individual and that working heights differ for precision work, light work and heavier work.

Woodson (1981) lists six conditions under which workers should stand. These include having to reach long distances, to reach laterally, to move frequently from task to task or place to place, to interface with others who are standing or working jointly with others at a large display area.

Pheasant (1991) recommends a varied working posture rather than a static posture. He maintains that it is a basic ergonomic necessity to provide suitable forms of seating for people who stand for prolonged periods. Woodson (1981) calls this the "sit-stand" configuration and only recommends this for people working at tasks lasting longer than 30 minutes.

1.12 Conclusions

The work reviewed above serves to illustrate those areas of standing work that have been investigated to date and does not cover all published research. However, considering the large portion of the workforce that stands and works, there is a relative paucity of work done on how fatigue and postural strain develop in prolonged standing. This can possibly be accounted for by a general belief in the "wisdom of the body", the belief that, given a workspace based on sound ergonomic and anthropometric principles, the body will sort the rest out.

The design of any product or environment should take posture into account - along with factors such as clearance, reach and strength. (Pheasant, 1987) The design of the workspace interacts with anthropometric variables to determine posture. Depending on the nature of this interaction, this posture is either constrained or unconstrained. The degree of constraint depends on the number and nature of the physical and visual connections between the individual and the workspace. Carson (1994) concludes that providing a well designed work area with the appropriate accessories, such as anti-fatigue mats and footrests, can minimise the stress and discomfort caused by prolonged standing.

However, according to Barlow (1990), even in the most perfect environment that ergonomics can construct, the "wisdom of the body" cannot resolve the conflict between those parts of the body required for task performance and those parts required to support the general functioning of the body. There is no "God-given" correct shape which is the only one appropriate for our human stance. Barlow maintains that we have actually reached the point where personal selection has to replace natural selection - we have to actually figure out and implement the next step of our postural evolution ourselves.

Sir Arthur Keith who was a leading authority on posture in the 1920's said, "it is not true, however, to say that our spines are not perfectly adapted to the upright posture; it would be more accurate to say that human spines are not evolved to withstand the monotonous and trying postures entailed by modern education and many modern industries." (Keith, 1923)

Also in the 1920's, Drew commented that man has become a "standing-around and sitting-down animal" with nearly all the activities of daily life encouraging a forward position of the arms and head. (Drew, 1926 in Zacharkow, 1988) Because of the position of the eyes and the nature of the joints, man is obliged to work in front of himself (even though some tasks also require "eyes in the back of the head" which, in practice, leads to unnatural twisting postures).

Fahrni (1966) suggests that we should avoid standing wherever possible. Kroemer (1987) claims that lying or half lying positions are suitable for certain types of work like computer operation. These suggestions are impractical in our society where people often have no alternative but to work for prolonged periods in a standing position.

Lest our postural adaptation to our environment dictates that we evolve into a tribe of primates with retracted necks, kyphotic humps and chronic lower back pain, it is in our interest to take a closer look at what happens to man as he stands working. When is he most relaxed? What causes him pain? When does he feel discomfort? How does he respond to the environment within which he works? In what ways might his work environment be altered to prevent or alleviate discomfort and pain? This thesis attempts to explore and answer some of these questions through four separate studies :

- a survey of standing workers in various industries
- a study of postural adaptations in standing workers to workbench modifications
- a study of postural adaptations in standing VDT work
- an evaluation of standing aids for the workplace

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2 - A SURVEY OF STANDING WORKERS AT FIVE DIFFERENT SITES

2.1 Introduction

In South Africa many people stand and work in a variety of occupations across a diverse set of industries. Many of these workers work under constrained conditions over prolonged periods. In order to gain some insight into the problems associated with standing work, a simple survey was conducted at five different sites.

The main aim of this survey was to explore the following :

- under what constraints and conditions standing workers operate,
- whether perceived discomfort is influenced by variables in the workplace,
- the length of time before musculoskeletal discomfort or pain is experienced and whether it is influenced by variables in the workplace,
- which areas of the body are experienced as uncomfortable or painful during the course of the working day.

This survey did not attempt to arrive at definitive conclusions and recommendations regarding standing work, but rather to provide a broader background for the laboratory studies which are reported in subsequent chapters.

2.2 Method

Subjects and Environments

Five sites were selected where workers were operating in a standing position throughout the working day. These sites included:

1. A clothing warehouse (**12 subjects**).
   In this warehouse, the people interviewed were employed as checkers (counting items into boxes), pickers (moving clothing from rails to boxes), unpackers (opening boxes and counting items out of boxes) and box makers (assembling cartons).

These workers were not confined to one spot as they had to walk occasionally, e.g. to another rail or to fetch a box.

2. A meat packing plant (**19 subjects**).
   In this plant, the people interviewed were employed as cutters (cutting meat) and packers (packing and wrapping meat in containers for supermarket outlets). The area where they worked was flanked by a refrigerated "picking area" which lowered the temperature of the room considerably. These workers tended to stand in one spot throughout the day and the lack of movement exacerbated the effect of the low temperature considerably.

3. A cardiothoracic theatre complex in a large teaching hospital (**4 subjects**).
   These subjects worked as theatre sisters, standing throughout operations on a small bench as the table was raised to be at an optimal height for the activities the surgeons and the rest of the team. These workers did effectively no walking during the course of their work, i.e. once they were confined to standing on the bench, they stayed there.

4. A factory manufacturing netting and twine (**19 subjects**).
   In this factory, the people interviewed operated looms, extrusion plants, twisting machinery, and they inspected bolts of netting and shadecloth for flaws. Some of these workers were able to move round more than others during the course of their working day. In general, however, those people operating equipment tended to remain very close to the looms or other machinery as they attended to these constantly. This often meant remaining in one confined space for a prolonged period.

5. A fashion retail outlet (**14 subjects**).
   In this store, people were employed as administration controllers, cashiers, sales assistants, showroom supervisors and manageresses. All the workers walked around a fair amount during the day, attending to customers, fetching and carrying merchandise and supervising the operation of the store.

A total of **68 subjects** were interviewed for this study.

Fig 2.1a Factory worker tending loom

Fig 2.1b Packers at work in warehouse

Questionnaire

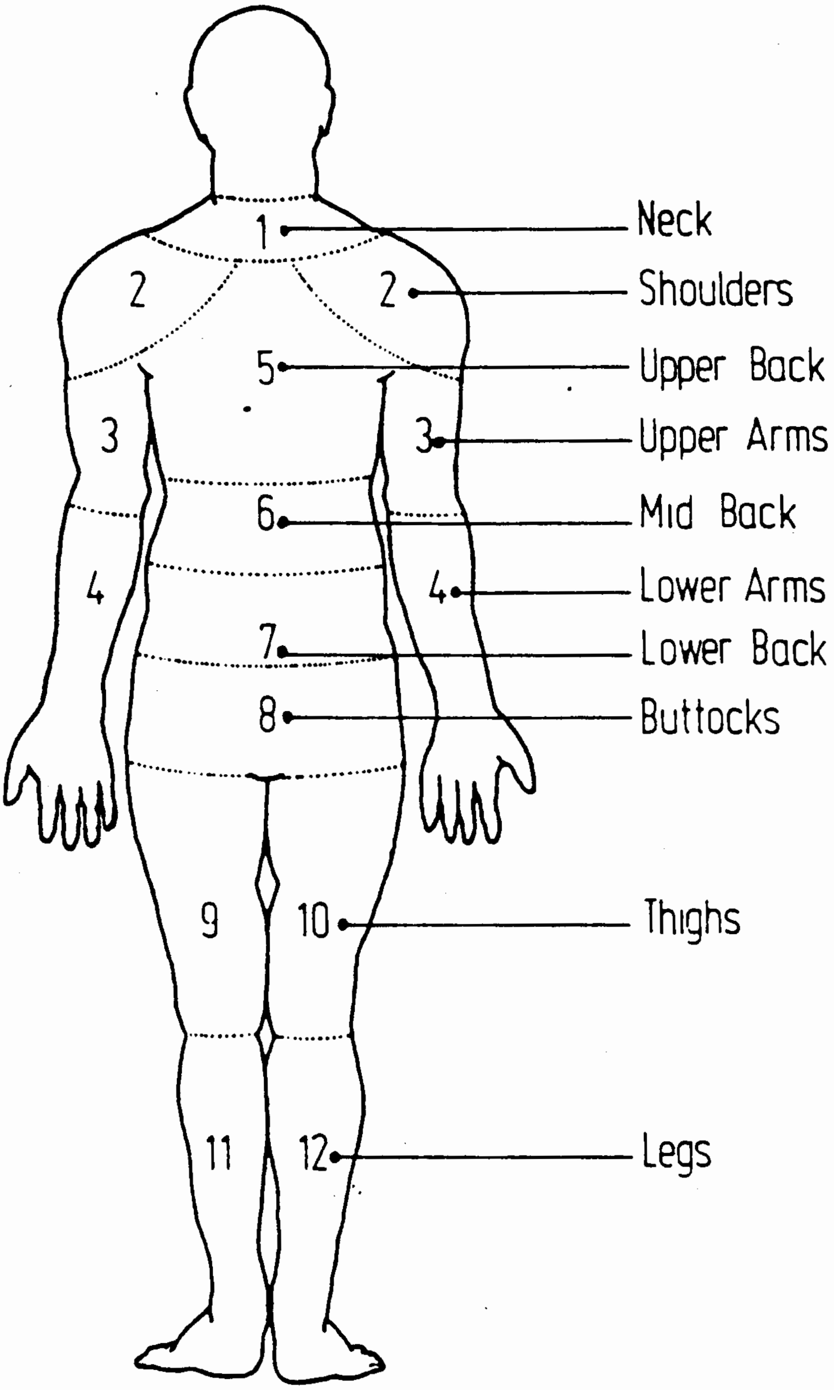
The questionnaire was administered by the same interviewer at all sites. The following questions were asked of each subject (where necessary the worker was observed at work in order to obtain answers to questions) :

- During the course of the working day, is the worker forced to assume postures that are constrained? (e.g. unable to move the feet, forced to reach forward or sideways). (Yes/No)
- Are any postures assumed which result in unnatural joint angles? (e.g. extremes of flexion or extension of the neck, trunk, hips, knees and ankles). (Yes/No)
- Are there prolonged static postures where the worker does not move or movement is minimal? (e.g. only writing, using a computer or a telephone). (Yes/No)
- Does the work entail using high velocity repetitive movements? (e.g. keypunch, sorting of papers). (Yes/No)
- Does the work include any lifting or carrying? (Yes/No)
- How many hours does the worker stand every day?
- After how many hours of standing does the worker become aware of any discomfort? (The workers indicated on the body diagram on the following page up to three areas where discomfort or pain was felt). See **Figure 2.2** on following page.
- How does this discomfort rate on a scale of 1 to 7? (where 1 represents the absence of discomfort and 7 represents severe discomfort or pain).

Figure 2.2 :

BODY DIAGRAM USED TO INDICATE DISCOMFORT OR PAIN SITES

(from Corlett and Manenica, 1980)



2.3 Results

Table 2.1 gives the percentages and mean results for all five sites.

Table 2.1

Site	Warehouse	Meat Packing	CT Theatre	Factory	Shop
% Constrained postures	91.6	100.0	100.0	100.0	100.0
% Unnatural joint angles	91.6	0.0	100.0	100.0	92.8
% Prolonged static postures	25.0	100.0	0.0	5.3	14.3
% High velocity repet. movements	100.0	100.0	0.0	100.0	14.3
% Some lifting and carrying	100.0	100.0	100.0	52.6	57.1
Average number of hours standing/day	7.0 sd = 0.0	8.0 sd = 0.0	5.0 sd = 0.0	8.45 sd = 1.15	7.25 sd = 0.93
Average number of hours before onset	5.33 sd = 1.23	5.37 sd = 2.06	2.75 sd = 1.26	5.08 sd = 2.95	5.75 sd = 1.67
Average discomfort rating	3.25 sd = 1.01	4.95 sd = 0.91	4.00 sd = 0.71	3.95 sd = 1.99	3.07 sd = 1.53
Most selected area of discomfort	11 - Legs (below knee)	7 - Lower back	7 - Lower back	7 - Lower back	11 - Legs

Workers in the meat packing plant were the only group that did not report activities that required the formation of unnatural joint angles. All workers at this plant reported the adoption of prolonged static postures during their working day. The theatre sisters were the only group to have no prolonged static postures except standing and to perform no high velocity repetitive movements during their work. These two groups, however, reported the highest discomfort.

Table 2.2 (next page) shows the overall means for all subjects.

Table 2.2 *Overall means for all subjects*

% Constrained postures	97.1
% Unnatural joint angles	69.1
% Prolonged static postures	36.8
% High velocity repet. movements	76.5
% Some lifting and carrying	77.9
Average number of hours standing/day	7.62 (sd = 1.13)
Average number of hours before onset	5.21 (sd = 2.07)
Average discomfort rating	3.93 (sd = 1.15)
Most selected area of discomfort	7 - Lower back (41.2%)

With the exception of **prolonged static postures,** most workers confirmed that their jobs involved those factors in the questionnaire which required a Yes/No reply.

Effect of workplace variables on ***perceived discomfort*** *:*

Table 2.3 shows the results of ANOVA (Kruskal Wallis) comparing the means of perceived discomfort ratings for each grouping within a variable.

Table 2.3. *Results of ANOVA with perceived discomfort ratings.*

Variable	**F-Ratio**	**p-value**
Site	17.495	.002 **
Constrained posture	3.779	.052
Unnatural joint angles	8.709	.003 **
Static postures	7.924	.005 **
Repetitive movements	4.771	.029 *
Lifting and carrying	14.698	.000 **
Hours standing	23.747	.003 **
Hours to onset	28.723	.003 **

** statistically significant at the 0.01 level

* statistically significant at the 0.05 level

The following can be noted from these results :

There was considerable variation across work sites in terms of perceived discomfort ratings. The following graph illustrates the average discomfort ratings for the various sites.

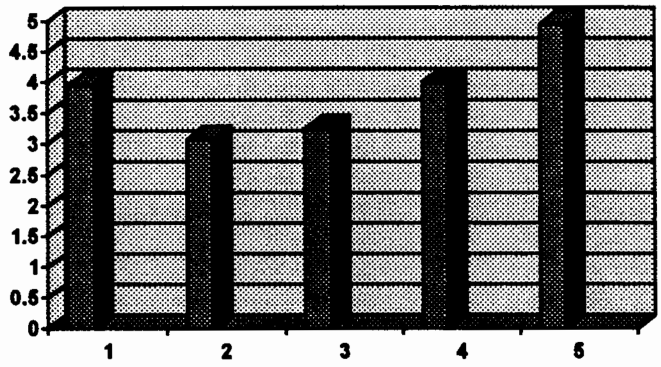


Figure 2.3. Average discomfort ratings by site. *(1=Factory; 2=Store; 3=Warehouse; 4=Operating theatre; 5=Meat packing plant)*

Having to form unnatural joint angles had a significant effect on discomfort rating. Those workers who reported unnatural joint angles had a mean discomfort rating of 3.61 (sd = 1.58) while those who did not had a mean discomfort rating of 4.64 (sd = 1.31). This is contrary to what would have been expected.

Maintaining static postures at points during the working day had a significant effect on discomfort rating. Workers who reported this to be the case had a mean discomfort rating of 4.54 (sd = 1.25) while those who did not assume static postures had a mean discomfort rating of 3.57 (sd = 1.64).

Performing repetitive movements had a significant effect on discomfort ratings with those workers reporting these having a higher mean discomfort rating (4.16; sd = 1.54) than those who did not (3.16; sd = 1.45).

Lifting and carrying during the working day had a significant effect on discomfort rating. Those subjects who reported lifting and carrying had a mean discomfort rating of 4.31 (sd = 1.39) while those who did not had a mean discomfort rating of 2.57 (sd = 1.44). In general, where lifting and carrying took place, discomfort tended to be greater than 3.5. Where lifting and carrying did not occur, discomfort tended to be rated less than or equal to 3.5.

Total number of hours standing during the working day had a significant effect on discomfort rating. Those workers who worked 7.5 or less hours per day (47.1% of the total sample) had a mean discomfort rating of 3.30 (sd = 1.41). Those workers who worked for longer than 7.5 hours per day (52.9% of the total sample) had a mean discomfort rating of 4.49 (sd = 1.51).

There was a very significant relationship between discomfort rating and hours before onset of perceived discomfort. Simple regression of discomfort rating and hours to onset of perceived discomfort yielded a highly significant F-statistic of 26.44. Regression analysis with hours to onset of discomfort as the independent variable and discomfort rating as the dependent variable resulted in a good linear model with a slope of 0.865 (sig. level < 0.01).

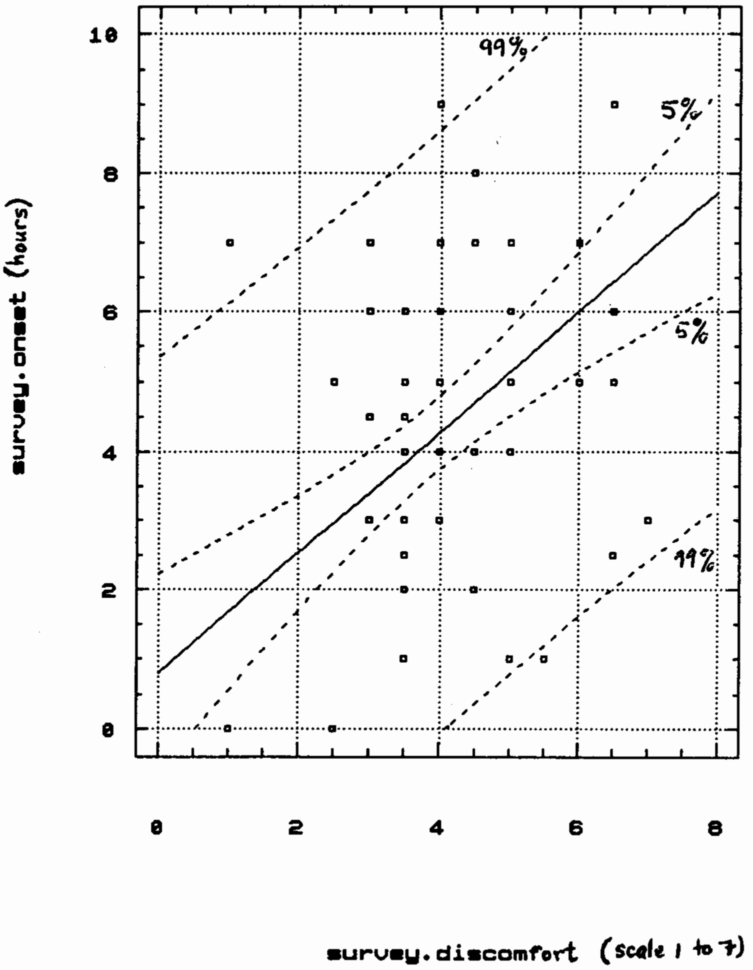
Closer examination of the results showed that when onset was reported at 4.5 hours or earlier, discomfort tended to be reported at 3.5 or less. When onset was later than 4.5 hours, discomfort tended to be reported at greater than 3.5. This trend is illustrated in the regression plot shown on the following page. While the results of the regression of discomfort rating and hours to onset are not strong enough to allow discomfort rating to be predicted from the hours to onset, the adjusted R-Square value of 28.6 shows that 28.6% of the variance in discomfort can be explained by the hours to onset of perceived discomfort.

Multiple regression analysis was used to examine explanatory models for *discomfort ratings* and the independent variables (total hours of standing per day, lifting and carrying, adoption of constrained postures, adoption of static postures, formation of unnatural joint angles, execution of high velocity repetitive movements and the work site.)

An optimal model was derived for *discomfort rating* which included the variables work site (sig. level < 0.01) and hours before onset of discomfort (sig. level < 0.01). The adjusted R-Square value was calculated at 0.397.

Where work site was excluded as an independent variable, a model was derived for *discomfort rating* which included lifting and carrying (sig. level < 0.01) and hours before onset of discomfort (sig. level < 0.01). The adjusted R-Square value was calculated at 0.323.

Figure 2.4 Regression plot of hours to onset of discomfort to severity of discomfort. (The dotted lines represent 5% and 99% confidence intervals.)



Effect of workplace variables on ***length of time before onset of discomfort:***

Table 2.4 shows the results of ANOVA comparing the means of hours to onset of perceived discomfort for each grouping within a variable.

Table 2.4. *Results of ANOVA with hours to onset of perceived discomfort.*

Variable	F-Ratio	p-value
Site	2.236	0.0742
Constrained posture	0.930	0.659
Unnatural joint angles	3.891	0.0498 *
Static postures	3.234	0.0731
Repetitive movements	1.785	0.1829
Lifting and carrying	19.005	0.0002 **
Hours standing	1.671	0.1243

** statistically significant at the 0.01 level

* statistically significant at the 0.05 level

The following can be noted from these results :

There was a significant relationship between the reporting of unnatural joint angles and the number of hours before discomfort was perceived. The results show that those workers who did not adopt postures with unnatural joint angles did not report the onset of discomfort before a mean of 5.10 (sd = 2.28) hours. Those workers who did report unnatural joint angles, found that they perceived discomfort much earlier (after a mean of 3.81 hours, sd = 2.57).

There was also a significant relationship between lifting and carrying and the number of hours before the onset of discomfort was reported. Those workers whose work included lifting and carrying, reported discomfort after a mean of 4.84 (sd = 2.28) hours while those who did no lifting and carrying, reported discomfort after a mean of only 1.97 (sd = 2.15) hours. This was contrary to what was expected.

Multiple regression analysis was used to examine explanatory models for *hours before onset of discomfort* and the independent variables (total hours of standing per day, lifting and carrying, adoption of constrained postures, adoption of static postures, formation of unnatural joint angles, execution of high velocity repetitive movements and the work site.)

A model was derived *for hours before onset of discomfort* which included the variables lifting and carrying (sig. level < 0.05) and discomfort rating (sig. level < 0.01). The adjusted R-Square value was calculated at 0.330. Examination of the results showed that lifting and carrying and later onset of discomfort were associated with greater perceived discomfort. This model is presented below :

Independent Variable	Coefficient	Std. Error	t-value	Sig. level
CONSTANT	0.298842	0.712037	0.4197	0.6761
discomfort rating	0.649802	0.182488	3.5608	0.0007
lifting and carrying	1.739277	0.685839	2.5360	0.0136

Body areas in which musculoskeletal pain and discomfort were perceived :

Figure 2.5 illustrates the distribution of primary areas (first choice) of discomfort reported by the 68 subjects.

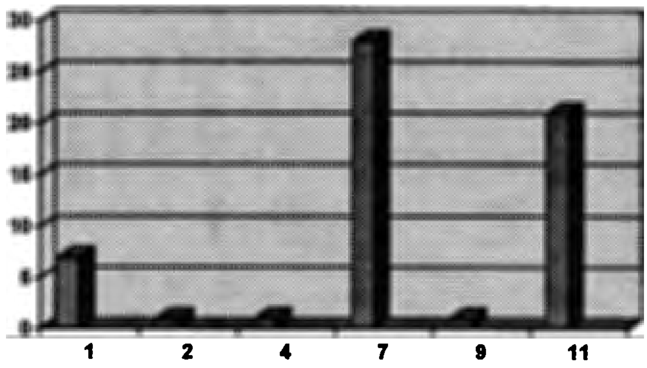


Figure 2.5. Number of subjects reporting different discomfort areas.
(1=Neck; 2=Shoulders; 4=Lower Arms; 7=Lower Back; 9=Thighs; 11=Legs)

From the above it is clear that lower back (28 out of 68, 41.2%) and legs (below the knees) (21 out of 68, 30.9%) were the most common sites of discomfort or pain. When the groups indicating lower back and legs were examined separately using simple regression, a more significant relationship was found between discomfort and onset (F-statistic = 11.05, df = 1) for lower back than for legs (F-statistic = 0.39, df = 1). For the lower back group, subjects tended to have later onset of discomfort associated with a higher discomfort rating than the group complaining of leg discomfort. For the lower back group, 57.7% reported discomfort greater than 4 while for the leg group, only 28.6% reported discomfort greater than 4.

These groups also differed in the total numbers of hours stood per day. For the lower back group, 76.9% worked for longer than 7.5 hours per day while for the leg group, only 33.3% worked for longer than 7.5 hours per day. This suggests that lower back pain is associated with longer hours of standing work. In addition, the mean duration before onset of discomfort for the lower back group was 5.43 hours (sd 1.77) while the mean duration before onset for the leg group was 4.21 hours (sd 2.54).

2.4 Discussion

<u>*Differences across sites :*</u>

The results in **Table 2.1 (page 55)** show that there was considerable variation across sites for average numbers of hours of standing per day, average number of hours before the onset of discomfort and the average discomfort rating experienced at a particular site.

Workers at the warehouse and the shop gave the legs as the primary area of discomfort or pain whereas workers at the other three sites indicated the lower back as the primary area of discomfort or pain. Workers at the warehouse and shop also were more mobile during the day than workers at the other sites. They also had lower mean discomfort ratings than workers at the other three sites. This suggests that walking reduces the discomfort felt by standing workers when on their feet for a prolonged period. It also suggests that increased mobility, while not removing discomfort altogether, does reduce the risk of lower back discomfort or pain.

Discomfort ratings :

Discomfort was significantly affected by all variables examined except the adoption of prolonged constrained postures. 97.1% of the workers interviewed had to adopt constrained postures. As a result, no conclusions can be drawn about the comfort levels of those two workers who did not have to adopt constrained postures. A larger sample of workers may yield different results.

There was a significant relationship between the formation of unnatural joint angles and discomfort ratings. Those who had to form unnatural joint angles had a lower mean rating than those who did not. This suggests that unnatural joint angles were associated with another variable which reduced discomfort, or that the absence of unnatural joint angles was associated with a factor that increased discomfort. It is possible that unnatural joint angles are associated with movement or more dynamic postures and that this prevented the stress placed on the soft tissues by prolonged immobility.

Examination of **Table 2.1** shows that almost all workers except those at the meat packing plant reported unnatural joint angles. It is possible, therefore, that the difference in discomfort is site-related and not due to the presence or absence of unnatural joint angles.

Discomfort rating is significantly related to work site. The nature of work varied widely from site to site. As the nature of work determines the extent to which the factors examined are called in to play, it follows that different sites should vary in terms of mean discomfort ratings. It is also possible that different sites have different "cultures", i.e. it may be more acceptable in one site to complain freely of pain and discomfort than it may be in another.

The regression model for discomfort rating included lifting and carrying and hours before onset of discomfort as having the highest association with discomfort. The picture that emerges is that onset is later where lifting and carrying are a factor. In addition, when onset is later **and** lifting and carrying are a factor, discomfort is greater.

Hours before onset of discomfort :

The regression model for onset is a reflection of the one for discomfort : lifting and carrying and the level of discomfort reported have the highest association with onset.

The absence of lifting and carrying from the work routine of the standing worker results in an earlier onset of discomfort although this discomfort is not rated as severely as the discomfort felt by those who do lift and carry but perceive the onset later. It is possible that those who lift and carry also are more mobile and that discomfort (even less severe discomfort) is perceived earlier by the workers who are less mobile.

Body areas where discomfort is perceived :

The results show that the lower back is the primary focus of discomfort, followed closely by the legs. Those complaining of lower back discomfort tended to experience later onset of discomfort which was more severe. By contrast, those complaining of leg discomfort tended to experience earlier onset of discomfort which was less severe. In addition, the former group stood longer during the day than the latter.

What this suggests is that in the course of prolonged standing, workers may first experience (less severe) discomfort in the legs. When they are required to stand longer, leg discomfort may become overshadowed by (more severe) discomfort in the lower back.

2.5 Conclusions

This survey draws attention to several interesting aspects of prolonged standing work. The results suggest that further research into the effect of duration of prolonged standing on pain sites and discomfort levels may provide some useful guidelines for optimal work periods and the timing and duration of rest periods. Further research into the effect of mobility on pain sites and discomfort levels may also provide useful data on minimising the risk of lower back pain or discomfort through interspersing prolonged standing with periods of movement. It would also be useful to quantify the exact effects of workplace variables like lifting and carrying, space constraints, the formation of unnatural joint angles and the use of high velocity repetitive movements on the timing and degree of discomfort due in standing workers.

Although the sample is not large enough to allow definitive conclusions and recommendations to be made, a potential rule that emerges from this data is that prolonged standing causes discomfort. The later this discomfort is reported, the more severe it is. Walking may delay the onset of discomfort and may also reduce the risk of lower back pain and discomfort. However, it appears that people who stand for longer than 7.5 hours a day, will have an increased risk of lower back problems.

Additional postural stresses due to the other variables (e.g. the inclusion of lifting and carrying) may overload a musculoskeletal system already stressed due to the effects of prolonged standing over years or even a worker's entire career. A potential recommendation would be to minimise these additional stresses on the system while not precluding mobility.

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3 - THE USE OF STEREOPHOTOGRAMMETRY AS A TOOL FOR POSTURE MEASUREMENT

3.1 Introduction

This section provides some background and motivation for the choice of stereophotogrammetry as a tool for posture measurement in the two studies which examine postural adaptations in standing workers. It also outlines the theory and the practical implementation of the method used.

3.2 Background

Herron (1972) suggests that the origins of biostereometrics can be traced as far back as the Renaissance when artists adopted the principle that art should faithfully represent nature. Realistic representation in painting and sculpture led to two practical problems : (1) how to obtain relevant information about three-dimensional objects that exist in the real world and (2) how to translate this information into a two-dimensional form. To a large extent, they overcame these problems by studying anatomy and skilfully applying this knowledge to their work.

However, it was Sir Charles Wheatstone who realised in 1832 that it was possible to reproduce the three-dimensional perspective we get with binocular vision by making two drawings from slightly different viewpoints and looking at these stereoscopically. He was the inventor of the stereoscope (from the Greek *stereos* meaning "solid" and *scopeo* meaning "I look at").

The basic principle of stereophotogrammetry is that of binocular vision. The eyes send slightly different images of an object to the brain, where they are interpreted in terms of depth as well as of length and breadth. Similarly, if two binocular or stereophotographs of an object are juxtaposed so that the left eye sees the left photograph and the right eye sees the right photograph in proper relation, the perception of depth can be as clear as if the object were seen clearly.

Biostereometrics (or biomedical stereophotogrammetry) began to develop with the appearance of the first double image stereocameras in the 1850's. As early as

1863, the physician Oliver Wendell Holmes used stereoscopic pictures to study human gait with a view to designing better artificial limbs for amputees during the American Civil War. Duchenne (1806 - 1875) photographed his patients in order to provide measurements of his deformed patients. However, photogrammetry "proper" is considered to date from the beginning of the 20th century. (Herron, 1972)

Photogrammetry (Greek: phos = light, gramma = writing) has been defined as the art, science and technology of obtaining reliable quantitative information about physical objects and the environment through the process of recording, measuring and interpreting images and patterns of radiant or transmitted energy derived from sensor systems.

During the 20th century, stereophotogrammetry has been mainly applied in aerial survey work although the potential for using the method in other areas, such as biology and medicine, has also been widely explored. As early as the 1920's, the usefulness of stereoscopic facts in the medical and dental fields were pointed out by researchers. (Hertzberg et al, 1957)

Biostereometrics is based on the principle that the surface of any biological structure can be regarded as an infinite number of points. If the three-dimensional co-ordinates of enough of these points are known for a particular application, a comprehensive measurement can be made for the part under investigation. Sheffer and Herron (1989) define biostereometrics as "the spatial or spatio-temporal analysis of biological form and function based on geometric and mathematical principles." The most versatile stereometric technique is stereo-photogrammetry, which provides a sound methodology for collecting information describing the shape of the human body in three dimensions.

In the past, stereophotogrammetric methods, although very successful, have been labour intensive and time-consuming which severely limited the scope and number of studies which could be performed. Development in solid state cameras, in computer hardware and in image processing technology have lead to real- or near real-time photogrammetry.

According to Sheffer and Herron (1989), the method has several major advantages. Among these are :

- the method is for the most part non-contact and does not distort the true shape of the human subject;
- it allows the subject to be examined relatively quickly as measurements are made afterwards from the photographic record;
- it provides a permanent record which is easily stored for retrospective examination using the same or an entirely different set of measurements;
- it has redundancy, i.e. it is possible to decide at a later stage which data is really needed for a particular study and the data can be used for more than one study;
- the apparatus is portable and can be used in a variety of experimental conditions;
- it is accurate to within 2mm in a measurement of 2 - 3 metres and this accuracy is independent of movement, and
- it is cost effective.

3.3 Stereophotogrammetry in Ergonomics Research

In many work environments, the design of the workplace determines the constraints on posture and movement. Studying the changes in posture and movement which are an integral component of task performance is therefore essential to the ergonomic assessment of a particular workspace design and/or task.

Several types of systems have been developed recently to quantify motion and dynamic posture in the workplace in three-dimensions. The two types of measuring devices most commonly used in the workplace to measure three-dimensional movement are electromechanical goniometers and video-based motion analysis systems. An example of the former is the Lumbar Motion Monitor developed at Ohio State University to quantify back motions (Marras et al, 1992).

When studying motions of a single joint, goniometers may be more accurate than video-based systems and are generally more useful for on-site evaluations.

However, among the liabilities involved with the use of goniometers are the fact that each joint requires a specially designed goniometer, the difficulty of monitoring more than one joint at a time, the need for frequent calibration checks and the cables or telemetry required for data transmission. (Lavender and Rajulu, 1995)

Video-based systems produce little interference with the subject's motions or tasks, are useful for studying several joints simultaneously, do not require the data collection hardware to be attached to the subject and have the added advantage that the video may provide other useful information about the workplace. Lavender and Rajulu (1995) however, discuss several disadvantages of video-based analysis systems. Among these are : the difficulty of setting up the cameras in limited-space work environments, the problem of retroreflective markers being obscured during movement on the job, variable lighting conditions, limited sampling frequency, lengthy data processing time and the effect of the presence of the cameras on the workers being observed.

The method used in the following two studies on postural adaptations derives postural angles in three-dimensions from a stereoscopic recording obtained with two video cameras. While this method has the disadvantages outlined above and is therefore not inherently suitable for portable on-site assessments, it possesses all the advantages of near real-time photogrammetry (listed previously) and these make it an ideal tool for posture assessment in a laboratory setting. Where the averages of relatively static postures are sought, the limitation on sampling frequency is not a problem.

Although postures and back shapes have been investigated biostereometrically by other disciplines (e.g. Turner-Smith and Thomas, 1989) (Pineau et al., 1986), stereophotogrammetry has been under-utilised in ergonomic research. As far back as 1972, Bullock and Harley (1972) evaluated stereophotogrammetry as a method of studying dynamic posture and they foresaw its continued use in ergonomics research, particularly in the field of dynamic anthropometry, where measurements of workspaces were sought.

However, researchers have favoured the use of linear measures which result in a two-dimensional posture description. (e.g. Raine and Twomey, 1994; Bridger, 1988; Mandal, 1985) A recent paper by Paul and Dowes (1993) compares posture recording with two-dimensional photography with posture recording by means of a three-dimensional optoelectronic system (Vicon). They conclude that two-dimensional posture recording and description can be used to gather useful data as long as measures are taken to prevent perspective error.

Two-dimensional posture recording has the advantages that it is inexpensive, easier to implement in the workplace, not hampered by unsuitable lighting conditions and does not require the use of advanced recording devices and computational techniques. However, it has the serious drawback that, like all two-dimensional "tape and caliper" methods, it ignores the fact that the human form is not composed of regular geometric shapes but *irregular*, three-dimensional components for which linear measures will not be able to provide unambiguous, comprehensive spatial quantification. While two-dimensional measurements are more convenient, their continued use will "help to perpetuate certain information gaps" (Herron, 1972).

3.4 Outline of the stereophotogrammetric method used in this thesis

The equipment (**Figure 3.1**) consisted of a Sanyo video cassette recorder with still picture playback (VHR-D500SA), an image mixer (Primebridge PVW1-Video Wiper), two CCD monochrome cameras (Burle TC650EX Series Cameras), two zoom lenses (Computar 8.5mm 1:1.3) and a Phillips monitor CM8833. The image mixer synchronised the two cameras and allowed the two images to be stored on a single video frame and to be displayed on the computer screen as a stereogram. This gave the added advantage that the subjects could be viewed on the videotape in stereoscopic mode, using the cross-eyed axis method (Adams, 1974).

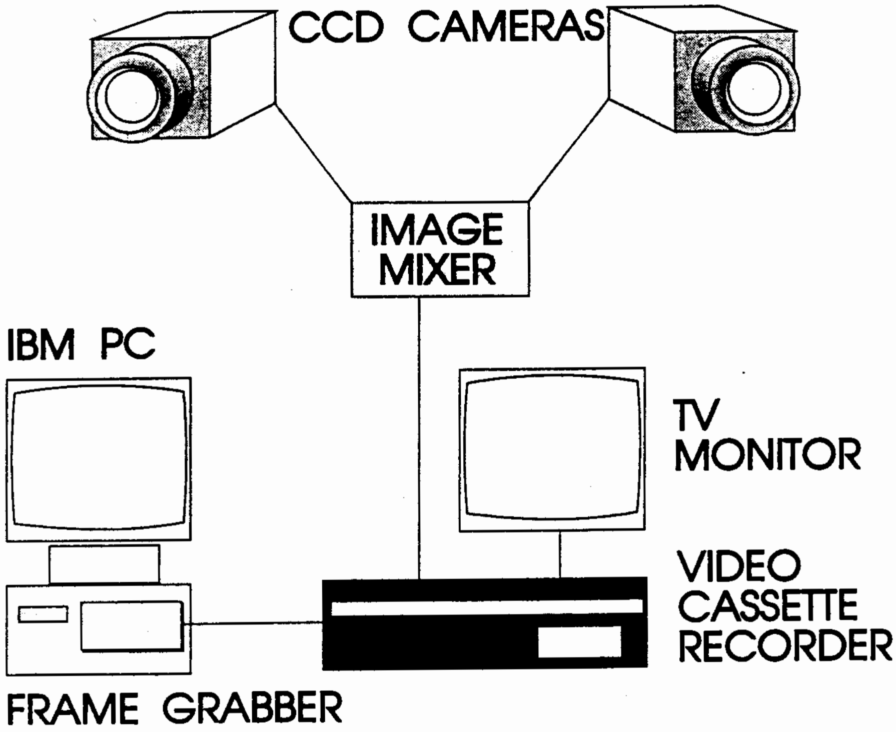

Figure 3.1 Diagram of the stereophotogrammetric equipment set-up.

The two video cameras were set up in stereometric mode and were initially used to record a fixed control frame on which there were 26 reference points made of retroreflective spheres. The control frame consisted of a heavy metal frame with a height and depth and width of 200cm, 66cm and 65cm respectively. The reference points therefore defined an approximate envelope within which the subject would stand and work. The exact positions of these reference points in space had been co-ordinated in three dimensions to high precision using traditional survey methods.

Figure 3.2 The control frame showing the position of the 26 targets. (Please note that black lines to the immediate left of each wire are shadows)

The software used to analyse the data, first developed in 1990 (Adams et al, 1990), has been updated several times (Adams et al, 1994). It is a near-real time photogrammetric system that is menu-driven.

The video machine was connected to the PC via the image frame grabber card. An image of the control frame was transferred to the PC and the two dimensional co-ordinates of the reference points were determined using semi-automatic target detection. (The operator was required to identify the border between the left and right image of the stereopair and to determine the threshold values for the images. In addition, while the targets were found automatically, they still had to be identified by the operator.) Precise target centres were determined using a centre of gravity detection algorithm.

Digitisation of these 26 targets on the left and right camera images allowed for the calculation of the positional parameters (camera constants) of the individual cameras using a method of projective transformation as discussed by Adams (1981). These parameters included the location of the camera base and the various tilts of the individual cameras.

The control frame was then removed and the subject stood within the area previously occupied by the control frame. Over the period that the subject was required to stand and work, positions of reflective body markers on the subject were recorded by the cameras. The images recorded by the two video cameras produced a stereopair.

The images to be measured were selected by viewing the split screen video and were captured on the PC with the image processing card. Only images of working postures were selected and selections were made at approximately 60 second (or 30 second for the VDT study) intervals. The four fiducial marks and the targets on the subject were then digitised so that the two-dimensional co-ordinates of image points on both the left and the right side were known. A computer program was then run using two-dimensional co-ordinates of the fiducial marks and a two-dimensional linear transformation to correct for any shift of the video frames. Such a shift could be due to the pause function of the video machine or to jitter within the CCD cameras. This same software then calculated the three-dimensional co-ordinates of the targets using the camera parameters. These co-ordinates were in a known system determined by the position of the two cameras and reference frame.

Figure 3.3 Photograph of the split-screen video showing the four fiducial marks to the left of each image.

A further computer program (written by the author) applying solid analytical geometry was then run to derive postural angles using the relevant spatial co-ordinates. The angles were defined by two lines whose direction cosines had been calculated by the two targets defining the line.

3.5 Neck flexion pilot study

A simple study was conducted to test the validity of postural angles determined from three-dimensional co-ordinates produced by this system. Four subjects (two females and two males) with an average age of 28.75 years (sd = 5.12) participated in the study. Markers were attached to the right temple, C7 and the right superior iliac crest. Subjects were videotaped as they flexed and extended the cervical region as far as they could. From the three-dimensional data calculated for the range of each movement, the range of flexion and extension in the sagittal plane was measured.

It was determined that the average range of flexion and extension for these four subjects was 95.5 degrees (sd = 12.15). This compares very well with the figure of 115 degrees given by Kapandji (1974) for the maximum range of flexion and extension in the cervical region. It must be borne in mind that Kapandji's maximum range applies to particularly supple individuals. The subjects used in this illustrative study were in good health and could be described as being of average physical fitness.

The stereophotogrammetric method was concluded to meet all the requirements for the laboratory-based studies on postural adaptations in standing workers.

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4 - POSTURAL ADAPTATIONS TO WORKBENCH MODIFICATIONS IN STANDING WORKERS

4.1 Introduction

In many work situations, operators must adopt a relatively fixed standing posture throughout the working day over a period of years or even a lifetime. van Wely (1970) found that there is a high correlation between postures repeated daily at work and specific pain sites. More specifically, Grandjean and colleagues (1968) concluded that prolonged standing in one place is a common cause of ailments affecting the legs and feet among saleswomen.

In the long term, postural misalignments at work increase the risk of disorders. Adaptation during prolonged standing is no exception to this (Floyd and Ward, 1967, Fox and Jones, 1967). Prolonged standing has been linked with a variety of symptoms, ranging from discomfort and fatigue which merely distract the worker and can be cured by rest; to serious long-term disorders like deterioration of the intervertebral discs, varicose veins and thromboses of the leg (Grandjean, 1980).

Basmajian (1985) points out that, once in the upright posture, man has the most economical anti-gravity mechanism of all animals. Fatigue is associated with direct tensions on inert structures and circulatory inadequacies (Basmajian, 1985). However, in order to maintain an upright posture with a minimum of muscular effort, the line of the centre of gravity must fall through the major weight-bearing joints and be equidistant from each foot (Roaf, 1977). Typical working postures rarely meet this requirement. Instead they force the centre of gravity away from the axis of rotation of knees, hips and spinal joints and so place strain on the muscles.

van Wely (1970) recommended that postures near the outer range of joint motions should be avoided as the relatively high load imposed results in discomfort and in the long-term increases the risk of disorders. A typical standing working posture involves bending forward. The most common way of doing this is arching the back in the thoracic region or bending from the lumbar region (Fox and Jones, 1967). According to these authors, the latter carries with it the tendency to use the pelvis as if it were part of the legs and the lumbar spine as a false joint, resulting in a large trunk flexion angle.

Nachemson (1976) found that bodily posture has a profound effect on intradiscal pressure. Leaning forward while standing was associated with 50% more intradiscal pressure than standing erect. Mosher (1913, 1914, 1919, in Zacharkow, 1988) stressed that standing posture is largely dependent on the position of the feet. Kirby et al (1987) found that foot position was an important determinant of standing balance.

When individuals need to stand relatively still for prolonged periods they adopt asymmetrical standing attitudes. It has been found that asymmetrical standing attitudes are adopted four times as often as symmetrical attitudes (Hellebrandt et al, 1943; Smith, 1953). Shifting the weight from foot to foot provides an important relief mechanism (Carlsoo, 1961).

In the commonly observed asymmetrical position, most of the body weight is carried on one leg with the other leg placed forward and to one side (Zacharkow, 1988). This stabilises the individual by providing a broader base of support as the main challenge in remaining upright in the symmetrical (feet together) position is maintaining the high body centre of gravity over a small support base.

Clinicians suggest that raising one foot onto a rail or footrest will result in a standing posture which is stable while leaving the hands free and, most importantly, by releasing the iliopsoas on the ipsilateral side, is deemed to prevent excessive spinal curvatures and thus remove stress from the intravertebral discs (White and Panjabi,1978; Fahrni, 1966). Provision of a footrest to reduce discomfort in standing is occasionally recommended in design manuals and standards such as the Code of Practice Manual Handling (1992). However, with the exception of Rys and Konz's study on the foot-forward position (Rys and Konz, 1989) few evaluations of subjects' postural adaptations to this way of standing have been carried out. Little is known about how the use of a footrest would interact with the visual and manual requirements of a given task.

This raised-leg position should result in a skeletal alignment similar to Mosher's "right foot twist" (Mosher, 1913, in Zacharkow, 1988). In this position, the right leg bears the weight while the left leg is directed diagonally forward. The pelvis tilts down to the left, the spine curves convexly to the right, the right shoulder is lowered and the head tilts to the right. Early researchers did not see this as a healthy alignment. They stressed that it was important to find a way of shifting body weight from side to side without the loss of body symmetry during prolonged standing (Lee and Wagner, 1949; Mosher, 1913, in Zacharkow, 1988).

More recent findings support the use of a footrest as a means of preventing excessive lordosis. Research has shown that tilting the pelvis posteriorly decreases the depth of the lumbar curve (Day et al, 1984; Bridger, 1988; Bridger et al, 1992). It is also known that flexion of the hip on the unsupported side results in tilting the pelvis posteriorly (Kapandji, 1970; Bridger and Orkin, 1992). From this it can be assumed that flexion of the hip on one side will result in some flattening of the lumbar lordosis.

Surveys in factories (e.g. Schierhout et al, 1993) have shown constrained standing to be a common working posture in many industries. The problems which have been observed are a lack of footspace due to design deficiencies or bad housekeeping (e.g. using the space around workstations as a temporary storage area) and constrained task distance (having to work with the hands at a distance from the trunk).

It was hypothesised that postural stress in standing could be exacerbated by design deficiencies in the workplace. A laboratory investigation was conducted to examine standing posture and perceived discomfort under three degrees of foot constraint and at two task distances. Postural stress was assumed to be present whenever standing posture forced the centre of gravity away from the axis of rotation of spinal joints, hips, knees and ankles, e.g. as in increased trunk flexion, neck flexion or hip flexion. It was further hypothesised that constrained foot position results in increased postural stress and an increase in perceived discomfort during prolonged standing.

4.2 Method

a) **Posture Measurement**

The investigation used a low-cost PC-based near real-time photogrammetric system for studying the posture of standing workers.

b) **Subjects**

Nine healthy male and nine healthy female subjects participated in the experiment. The mean age for the males was 25.7 years (sd = 3.28) and the mean age for the females was 27.1 years (sd = 4.81). The mean stature for the males was 177.9 cm (sd = 6.45) and the mean stature for the females was 164.2 cm (sd = 2.95).

c) **Apparatus**

The computerised system consisted of the following:

- Sanyo video cassette recorder with still picture playback VHR-D500SA (digital),
- 10 Phillips video tapes,

- two channel image mixer (Video Wiper PVW-1),
- 2 CCD monochrome cameras (Burle TC652EX Series Cameras),
- 2 zoom lenses (Computar 8.5mm 1:1.3), Phillips monitor CM8833,
- control frame with three-dimensional co-ordinated control points,
- vertically mounted mirror 1mx1m,
- 2 lamps with 100 watt globes and dimmer,
- MBM 32 personal computer,
- Matrox PIP-512 image processing card,
- fiducial markers mounted on stand.

Other equipment used was : Black-painted workbench with adjustable height, foot-rail to test the hypothesis that use of a footrest reduces postural strain during standing and a removable board which prevented the subject from placing his feet under the workbench. **Figure 4.1** shows a subject at work in the laboratory.

Figure 4.1. Subject being videotaped while at work in the laboratory setting.

d) **Procedure**

Semi-nude subjects who had already been standing for one hour were prepared by sticking spherical reflective markers mounted on 15mm stalks on the skin over vertebra prominens, the tips of 7 spinous processes, the dimples over the posterior superior iliac spines and the right anterior superior iliac spine. Flat reflective markers were also stuck on the right side over the skull behind the ear, over the greater trochanter, the knee joint, the ankle joint and the little toe.

In order to test the hypotheses that foot position and task distance influence standing posture, the subjects were videotaped as they worked on a jigsaw puzzle at the workbench in a laboratory with black walls. The bench was adjusted for each subject so that the work surface was just below elbow height. Subjects worked at a task distance that was either constrained, i.e. required reaching to the far side of the work surface, or unconstrained. In addition to this, foot position was constrained by a board, unconstrained (there was toe space under the bench) or a footrail on the bench was available.

This gave six different experimental conditions under which the subjects worked, in random order, for ten minutes each:

A - Task distance unconstrained, unconstrained foot position.
B - Task distance unconstrained, constrained foot position.
C - Task distance unconstrained, use of foot rail.
D - Task distance constrained, unconstrained foot position.
E - Task distance constrained, constrained foot position.
F - Task distance constrained, use of foot rail.

A mirror was positioned so that it reflected the markers on the subject's back when they were obscured by the body. **Figure 4.2** (next page) shows a subject working under the six different experimental conditions.

Figure 4.2. Subject at work under the six different experimental conditions.

A - Task distance unconstrained, unconstrained foot position.

B - Task distance unconstrained, constrained foot position.

C - Task distance unconstrained, use of foot rail.

D - Task distance constrained, unconstrained foot position.

E - Task distance constrained, constrained foot position.

F - Task distance constrained, use of foot rail.

After working under each experimental condition, the subject was asked to rate the work space on a seven-point comfort scale in which a score of 1 corresponded to very comfortable and a score of 7 to very uncomfortable. In addition, the subject was asked to indicate up to three body zones where any discomfort was detected while working under each set of constraints. The body zones were: neck, upper back, mid back and lower back; shoulders, upper arms and lower arms; buttocks, thighs and legs. (See **Figure 2.2**, page 54)

e) Observation and mathematical procedures

The images to be measured were selected by viewing the split screen video and were captured on the personal computer equipped with the image processing card. Only images of working postures were selected and selections were made at approximately sixty second intervals. For positions C and E which employed the footrail, image selection had the added criterion that the leg closest to the camera had to be the supporting leg.

Each image was then digitised so that the two dimensional co-ordinates of image points on both the left and the right side were known. A computer program was then run using the two-dimensional co-ordinates of the fiducial marks and a two-dimensional linear transformation to correct for shift of the video frames due to the pause function of the video machine.

This same software then derived the three-dimensional co-ordinates of the points on the body by a method of projective transformation as discussed by Adams (1981). Where three-dimensional co-ordinates corresponded with points beyond the plane of the mirror, i.e. where mirror image points were selected and digitised, a further transformation was performed in order to translate these points from the mirror image space to the body space.

f) **Presentation of results**

A further computer program (written by the author) was run to derive postural angles using the relevant spatial co-ordinates. The program calculated seven average postural angles for each subject under each of the six experimental conditions.

The seven postural angles are illustrated in **Figures 4.3, 4.4a** and **4.4b**. It is important to emphasise that although the illustrations suggest that these angles exist along one spatial plane, they are oriented in three dimensions, as they manifest on the subject. The seven postural angles were defined as follows:

1) Trunk Flexion (TF): The angle between the upper trunk line and the upward extension of the pelvic line. TF decreases with increased forward bending of the trunk.

2) Hip Flexion (HF): The angle between the thigh and the downward extension of the pelvic line. HF increases as the hip joints are flexed.

3) Pelvic Inclination (PI): The inclination of the pelvic line with respect to the horizontal. PI increases as the pelvis tilts forwards.

4) Trunk Inclination (TI): The inclination of the trunk with respect to the horizontal. Large values of TI mean more inclination over the work surface while small values correspond to an upright position.

5) Neck Flexion (NF): The angle between the upward extension of the trunk line and the line from the seventh cervical marker to the skull marker. NF increases as the head is bent forward.

6) Knee Flexion (KF): The angle between the lower leg line and the extension of the thigh line. KF increases as the knee is flexed.

7) Plantar Flexion (PF): The angle between the lower leg line and the line from the ankle marker to the little toe marker. PF decreases as plantar flexion increases.

With the exception of Plantar Flexion these angles are based on the two-dimensional postural angles defined in Bridger (1988).

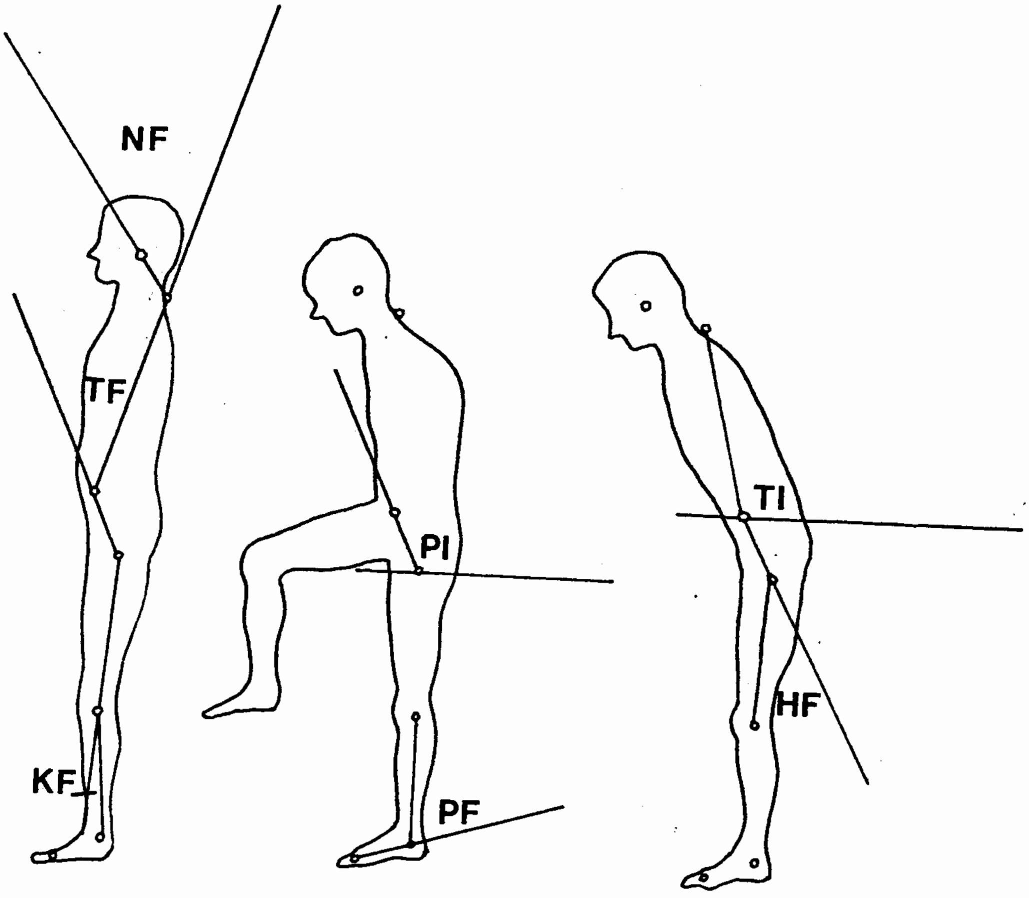
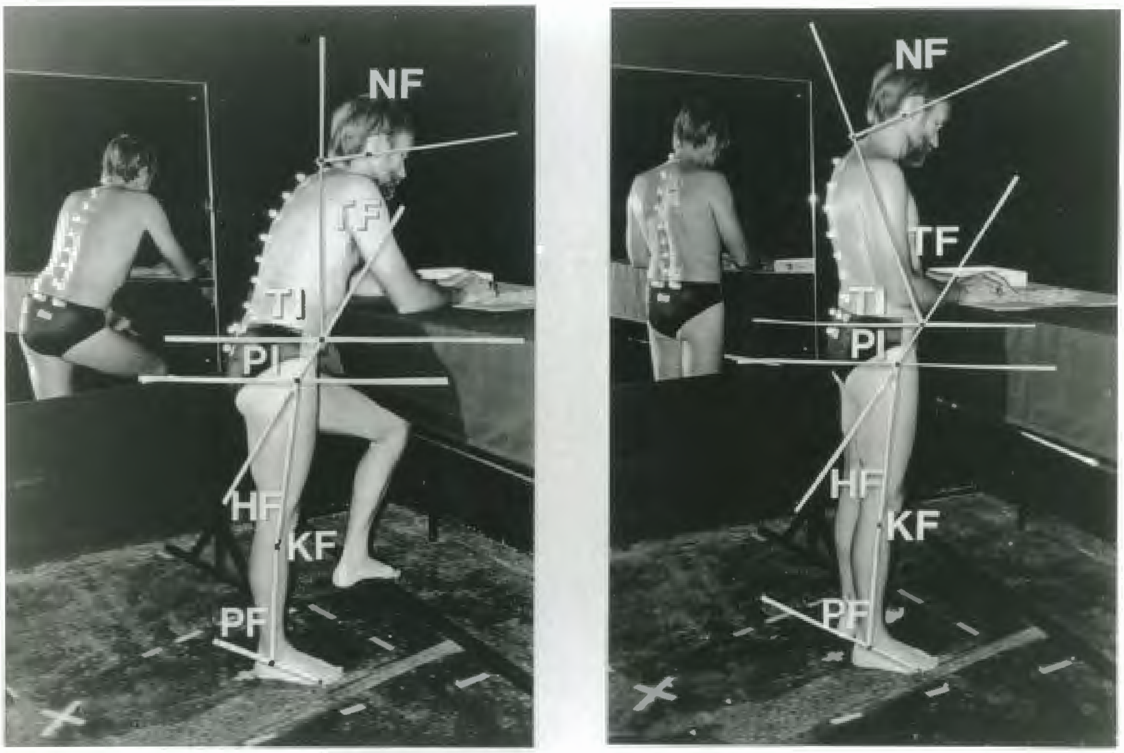


Figure 4.3. Location of skin markers used to derive the seven postural angles.

2



(a) (b)

Figure 4.4. Postural angles demonstrated on the subject working at the workbench.

(a) At constrained task distance with use of the footrail.

(b) At unconstrained task distance with foot position unconstrained.

Additional software found the average orientation in space for the spinal and pelvic markers for all subjects for each experimental condition. These were plotted out as stereo-triplets to be viewed stereoscopically. The perspective from which the stereo-triplets were viewed could be pre-defined. Stereo-triplets could also be printed out for individuals.

4.3 Results

Effects of Workstation Factors on Postural Variables

For each of the seven postural variables, the data were treated as a mixed 2 X 2 X 3 design of two fixed factors with subjects as a third (random) factor and 10 observations per cell.

Table 4.1 presents the grand means for each constraint/variable combination over all subjects. **Table 4.2** presents the results of ANOVA for the comparisons between these means.

Table 4.1 Means and standard deviations (sd) of postural angles (in degrees) for the six design constraints.

Constraints /	***Unconstrained Task Distance*** /			***Constrained Task Distance***		
Postural Variable	**Unconstrained Foot position**	**Constrained Foot Position**	**Use of Footrail**	**Unconstrained Foot position**	**Constrained Foot Position**	**Use of Footrail**
Trunk Flexion						
mean	43.9	43.5	39.1	33.0	32.2	29.9
sd	9.6	11.2	12.6	10.1	10.5	9.9
Hip Flexion						
mean	39.9	40.2	39.5	44.4	45.4	42.4
sd	12.1	11.4	10.3	11.6	11.9	10.6
Pelvic Inclin.						
mean	130.0	130.2	128.3	134.5	137.1	132.0
sd	11.5	11.3	11.3	11.3	10.8	11.4
Trunk Inclin.						
mean	90.9	91.5	93.6	106.2	109.3	109.1
sd	8.8	8.0	9.9	6.5	6.7	6.5
Neck Flexion						
mean	93.0	92.2	90.4	82.4	80.3	82.8
sd	12.3	11.8	10.9	7.5	13.5	12.0
Knee Flexion						
mean	7.5	8.3	6.7	8.2	7.7	6.6
sd	2.5	3.4	2.8	2.7	3.0	2.5
Plantar Flexion						
mean	77.2	75.6	80.5	75.7	74.4	79.2
sd	4.1	4.8	3.2	4.1	2.7	3.5

Table 4.2. F-Ratios from the analysis (by ANOVA) of the effects of sex (A), task distance (B) and foot position (C) on the seven postural variables.

		POSTURAL VARIABLE						
Factor	**df**	**TF**	**HF**	**PI**	**TI**	**NF**	**KF**	**PF**
A	1	0.0	0.7	0.5	1.7	0.2	0.6	0.0
B	1	** 54.8	** 48.7	** 62.4	** 89.7	** 31.0	0.2	8.1
C	2	** 8.6	* 4.2	** 19.8	2.8	0.7	** 10.6	** 65.2
A X B	1	1.3	0.8	0.0	1.3	0.0	-0.2	0.0
A X C	2	1.5	-0.1	* 3.9	0.6	2.5	2.9	0.0
B X C	2	0.6	2.8	* 5.9	0.8	1.1	1.8	0.1
A X B X C	2	1.6	1.3	0.8	0.5	2.6	0.7	0.0

** Statistically significant at the 0.01 level.

* Statistically significant at the 0.05 level.

These results are presented graphically below. (Note: Foot position (1) is unconstrained, (2) is constrained and (3) uses the foot rail.)

Figure 4.5 ***Graphical representation of effects on task distance and foot position on postural variables***

Figure 4.5a

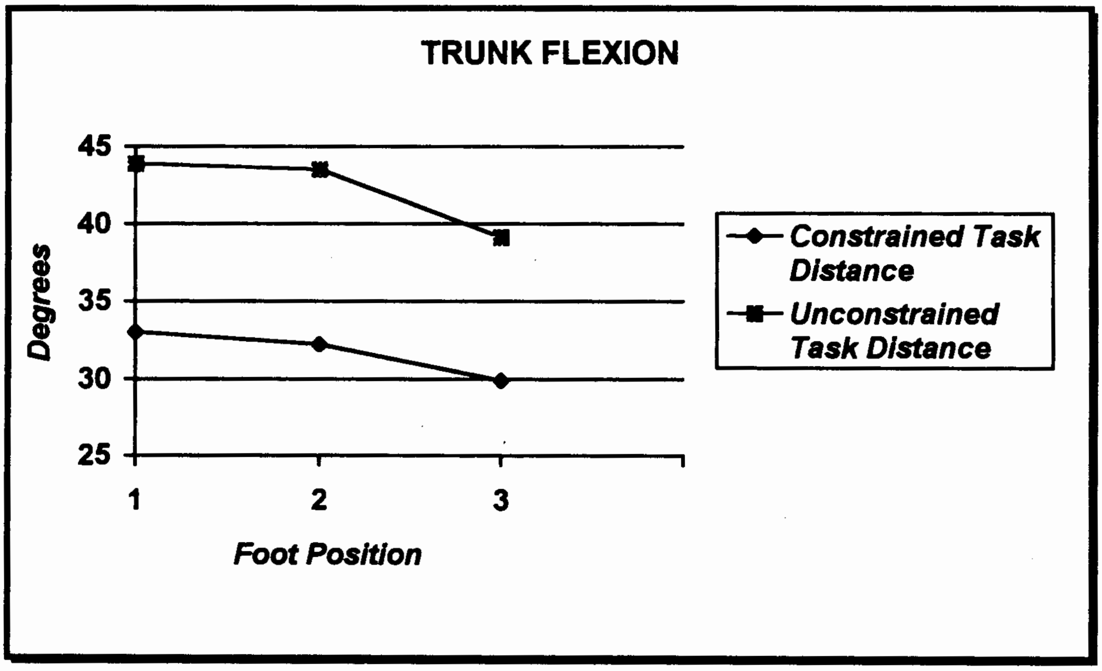


Figure 4.5b

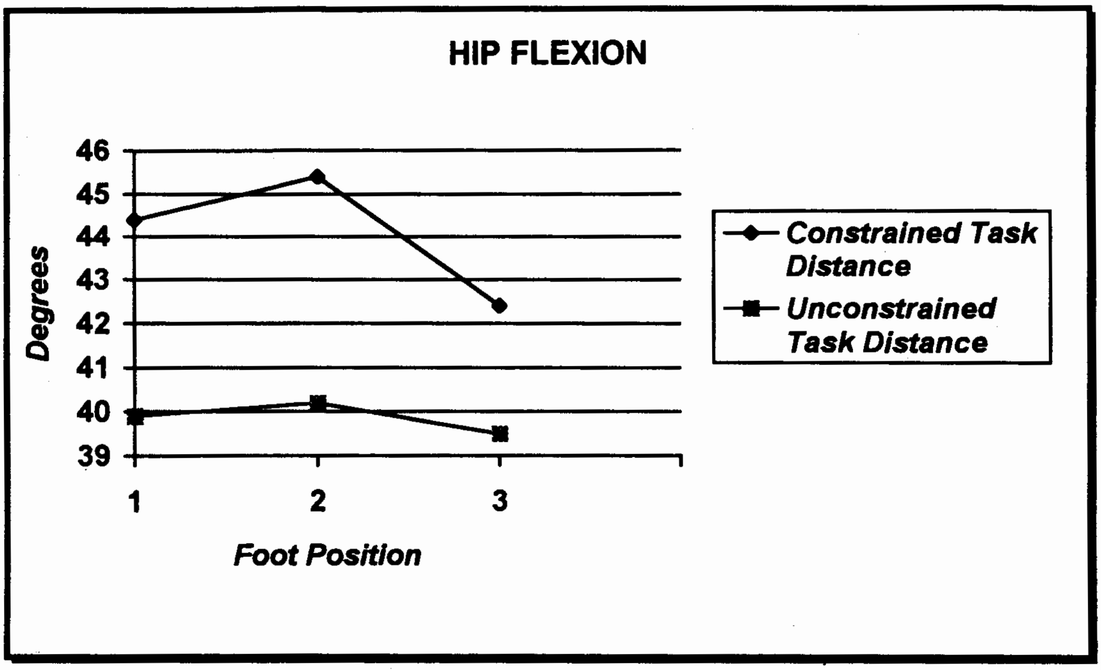


Figure 4.5c

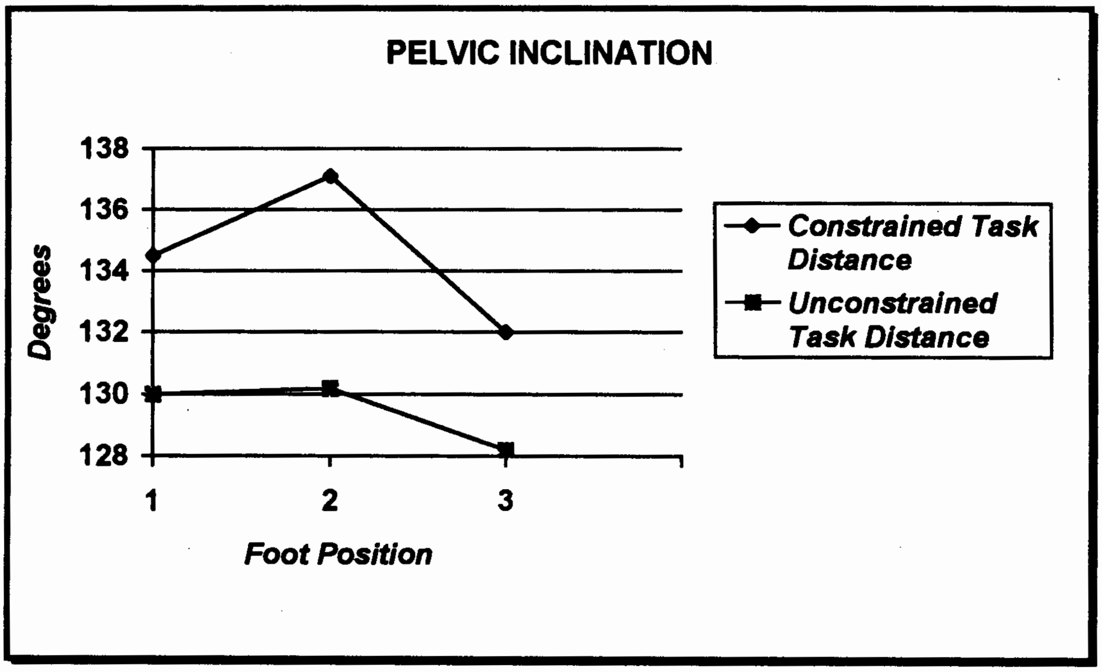


Figure 4.5d

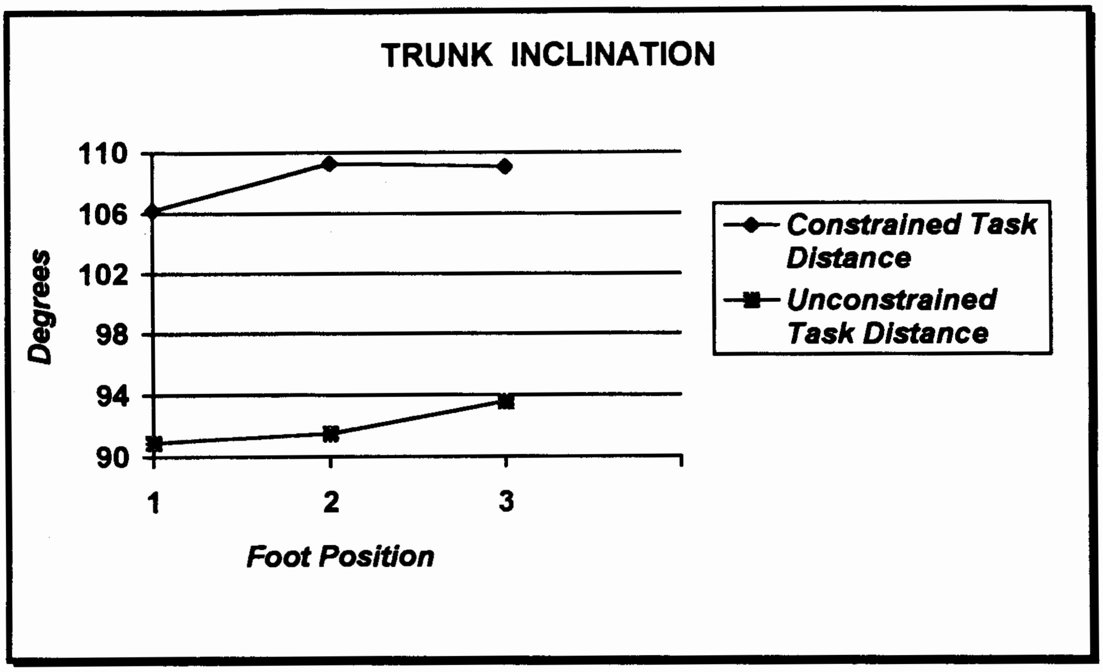


Figure 4.5e

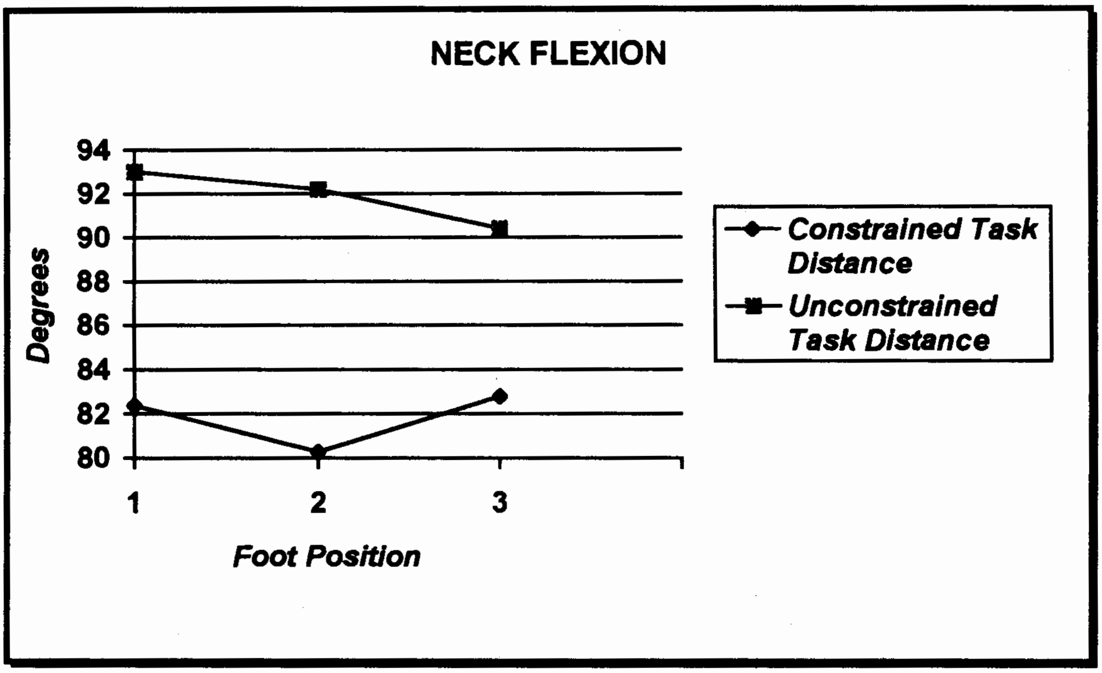


Figure 4.5f

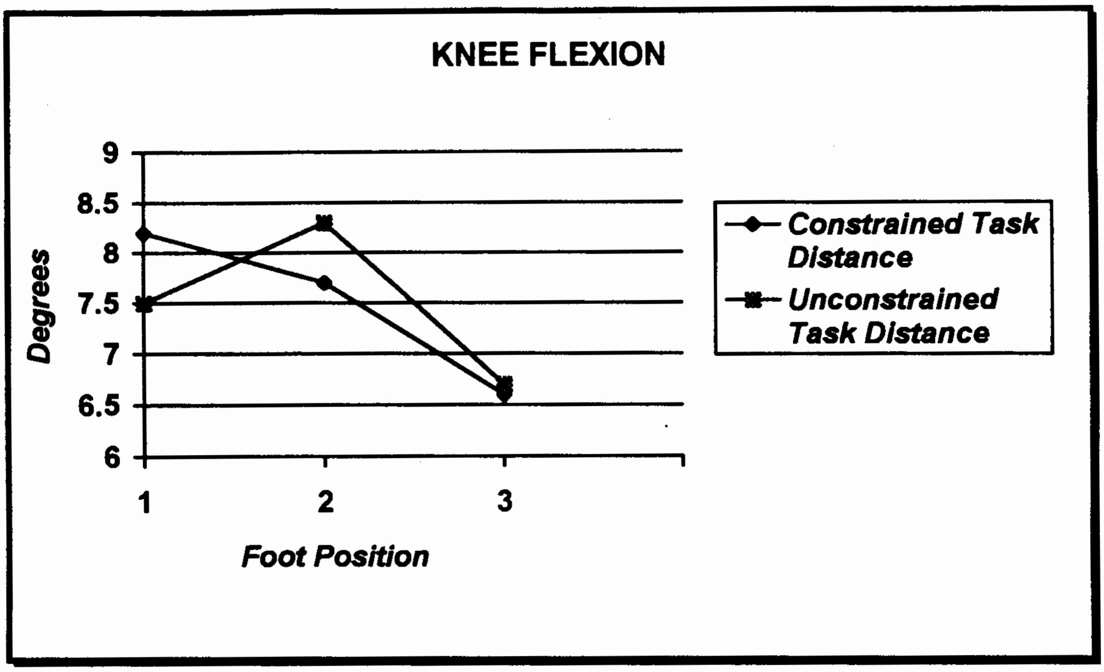
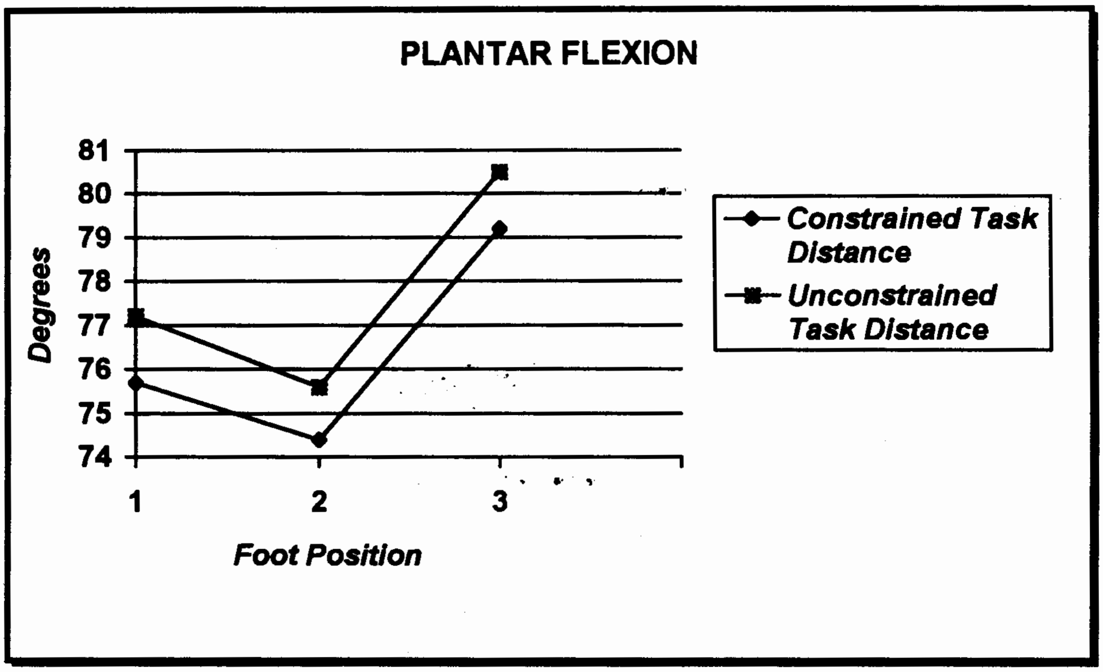


Figure 4.5g



In sum, gender was not found to have any significant effect on postural adaptation to workstation constraints. Task distance was found to have a significant effect on posture. Constrained task distance resulted in more trunk flexion, more hip flexion and greater pelvic and trunk inclination than unconstrained task distance. Unconstrained task distance resulted in significantly more neck flexion than constrained task distance.

Foot position had a significant effect on trunk flexion, hip flexion, pelvic inclination, knee flexion and plantar flexion. In particular, use of the footrail resulted in more trunk flexion and reduced pelvic inclination. It also resulted in reduced hip flexion, reduced knee flexion and increased plantar flexion on the supporting side. The constrained foot position resulted in increased hip flexion and increased pelvic inclination, particularly for the constrained task distance. It also resulted in less plantar flexion for both task distances.

Comfort

Subjects rated the work spaces on a seven-point scale (1 = very comfortable, 7 = very uncomfortable). **Table 4.3** summarises the mean comfort ratings for the work spaces.

Table 4.3. Mean comfort ratings for the six workspaces.

Constraints /	***Unconstrained Task Distance /***			***Constrained Task Distance***		
Postural Variable	**Unconstr. Foot Position**	**Constr. Foot Position**	**Use of Footrail**	**Unconstr. Foot Position**	**Constr. Foot Position**	**Use of Footrail**
Mean Comfort Rating	2.52	2.43	2.60	2.60	2.52	2.70

The comfort ratings were analysed using Friedman's two-way ANOVA by ranks, which yielded the result Chi-square = 3.33, df = 5, p = 0.65. There was therefore no significant relationship between subjective comfort rating and work space constraints.

Table 4.4 indicates the areas of discomfort most frequently indicated for each of the experimental constraints while **Table 4.4a** indicates the frequency of reporting areas of discomfort overall.

Table 4.4. (see above for definition of constraints).

Constraint	Frequency (%)	Zone (or Zones) of Discomfort
A	39	Neck
B	45	Neck
C	55	Thigh and leg on supporting side
D	36	Both legs
E	44	Both legs
F	42	Thigh and leg on supporting side

Table 4.4a Frequencies of reporting body areas overall

Body area	Frequency (%)
Neck	23.9
Shoulders	9.9
Upper Arms	6.3
Upper Back	7.0
Mid Back	2.1
Lower Back	11.9
Buttocks	2.1
Thighs	10.6
Legs and Feet	26.0

4.4 Discussion

Sex:

Bridger et al (1992) found that gender had a statistically significant effect on lumbar angle, the angular measure of lumbar curvature. Fully extended lumbar lordosis in standing was found to be greater in males than in females. In addition, they found that the greater hip muscle length of females was correlated to a greater range of pelvic tilt.

These findings suggest that there may be sex differences in postural adaptation, particularly in pelvic inclination (PI). However, no significant difference was found between male and female subjects in their postural adaptations to the different standing workstations.

Task Distance:

Task distance was found to have a significant effect on posture, particularly on trunk flexion, hip flexion, pelvic inclination, trunk inclination and neck flexion. Trunk inclination, which is an indicator of the degree of inclination with respect to the horizontal, increased when the task distance was constrained. Fox and Jones (1967) found that when dentists bent forward to work, they tended to do so from the lumbar region or arch the back more in the thoracic region as opposed to bending forward from the hips. The former tendency is substantiated in this study as increased trunk inclination, accompanied by an increase in trunk flexion, shows that subjects flexed the trunk forward above the pelvis in order to work further away.

Trunk flexion is closely coupled to trunk inclination although the former is dependent on the orientation of the pelvis. Trunk flexion increased substantially when the task distance was constrained. In the same study, Fox and Jones (1967) found that operators tended to use the pelvis as if it were part of the legs and so make a false joint of the lumbar spine. Increased trunk flexion indicates that the latter is the case.

However, the pelvis was not held completely stationary. When task distance was constrained, pelvic inclination and hip flexion increased, showing that flexion from the lumbar region was accompanied by some pelvic adaptation. As the lower limb posture did not change significantly for task distance, hip flexion was increased due to forward inclination of the pelvic line.

Thus, postural adaptation to increased task distance is characterised by increased flexion at the lumbar region (trunk flexion) and increased flexion at the hip, accounted for by increased pelvic inclination.

Working at the unconstrained task distance, subjects were found to have more neck flexion than at the constrained task distance. The task was visually demanding and when it was placed directly in front of the subject, it required constant looking down. This sustained acute neck flexion is supported by the finding that for both workstations A and B, the area of discomfort most frequently indicated by subjects was the neck.
Postural adaptation to task distance thus involves a trade-off between neck flexion and trunk flexion. Neck flexion is reduced when task distance is increased while the opposite is true for trunk flexion.

The stereo-triplets in **Figure 4.7** depict in three dimensions the average postural adaptation of the back and pelvis to each of the six workstations as seen from the front. **Figure 4.6** illustrates on the subject exactly which points are used in the stereo-triplets, point C being a projected point corresponding to the left superior anterior iliac spine, while D is the right superior anterior iliac spine, and A and B are the superior posterior iliac spines.

The stereo-triplets confirm the above findings. Comparing stereo-triplets A, B and C with D, E and F, it is clear that constrained task distance results in more flexion above the pelvis, more forward tilting of the pelvic plane and less neck flexion. Besides increased neck flexion, the stereo-triplets for the unconstrained task distance reveal some increase in thoracic kyphosis.

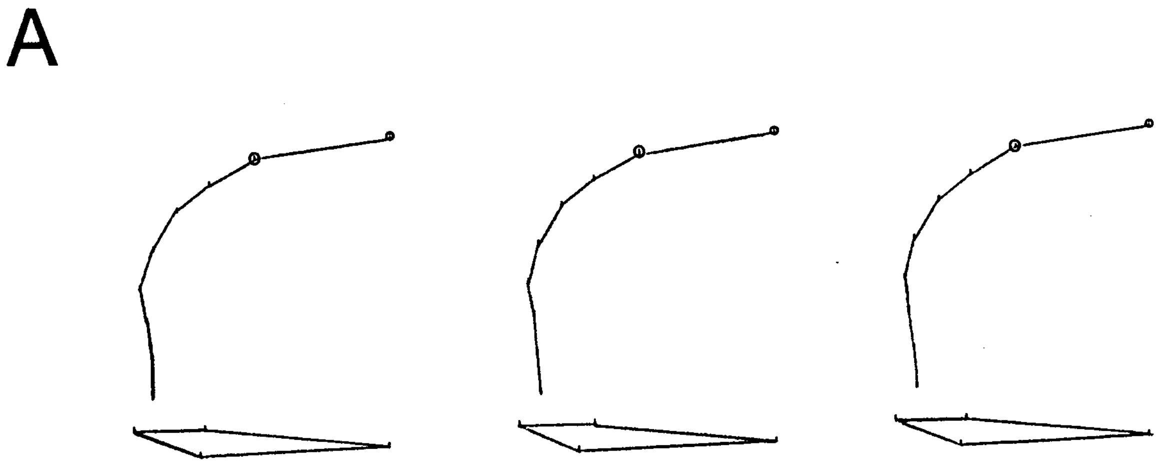
This may, like increased neck flexion, be an adaptation to having a visually demanding task lying flat on the workbench directly in front of the subject. From the stereo-triplets it is clear that when task distance is increased, the thoracic kyphosis is flattened and the trunk flexion is increased.

Figure 4.6. Location of all points on the subject used to obtain the stereo-triplets. The position of point C is determined from the positions of the points A, B and D. "C" on the mirror image shows approximately where the point C should be reflected.

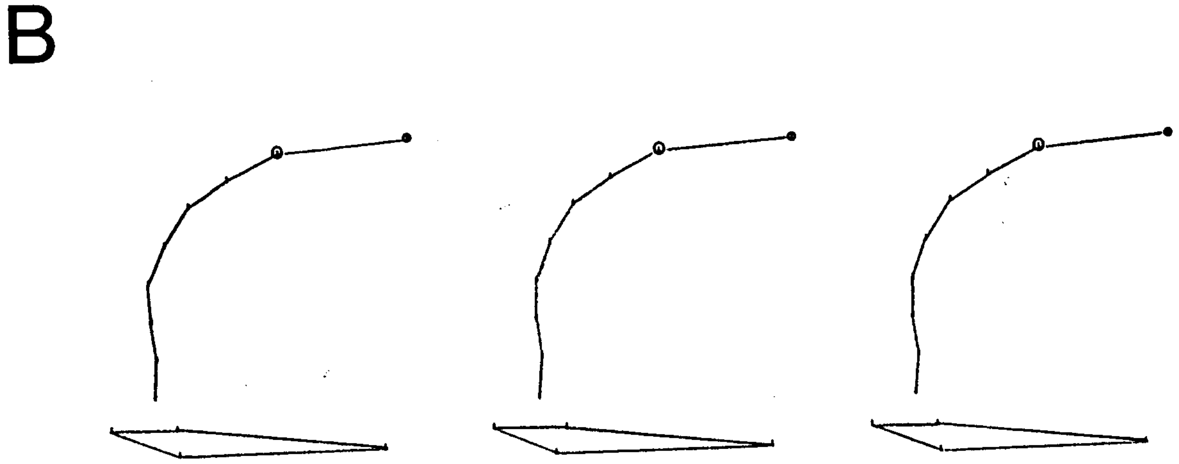
Figure 4.7. (following two pages) Stereo-triplets showing the average postural adaptation of back and pelvis to each of the six workstations as seen from the front.

***Note:** Stereopsis of any two adjacent members yields two spatial images with reversed depth. The stereoscopic effect can easily be achieved either by viewing the triplet with the naked eye using the parallel eye method or by the cross-eye method, in which case the "depth" will be reversed. For untrained eyes, a simple hand stereoscope can be used to achieve stereoscopy. In this case, only two of the images should be looked at, not all three images in the triplet*

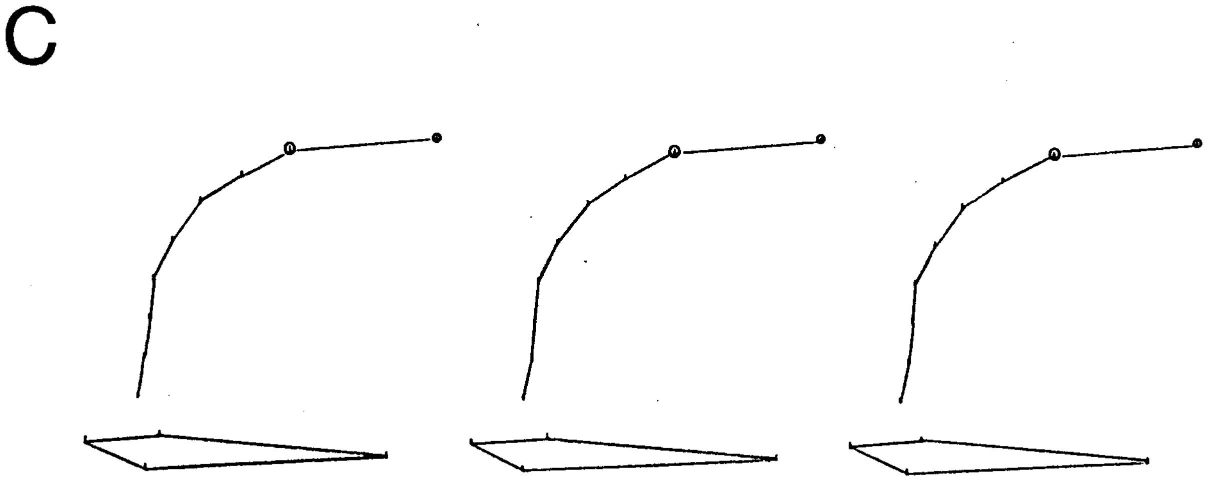
Figure 4.7 Stereo-triplets showing average postural adaptations of back and pelvis for the different workstations.



A - Task distance unconstrained, unconstrained foot position.

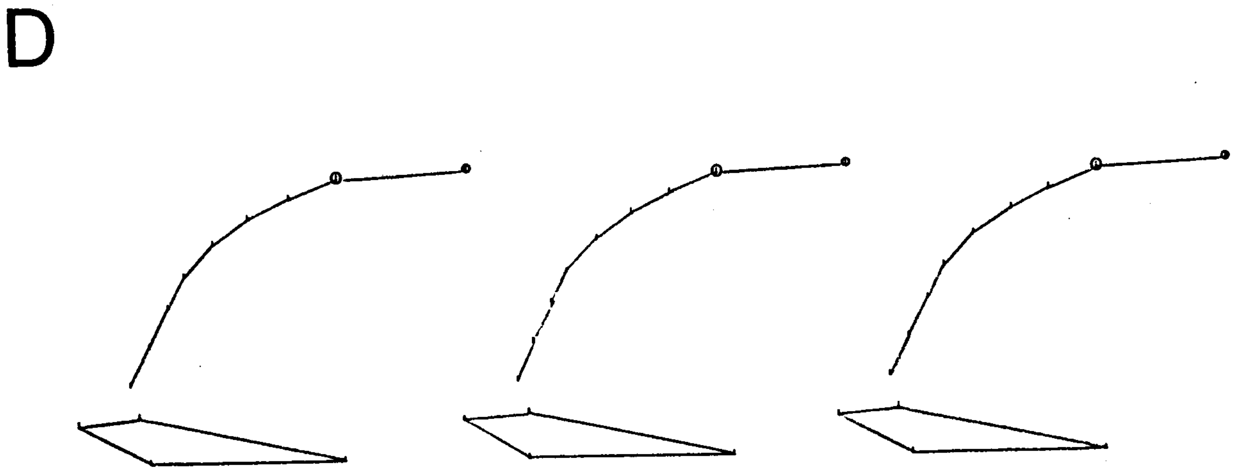


B - Task distance unconstrained, constrained foot position.

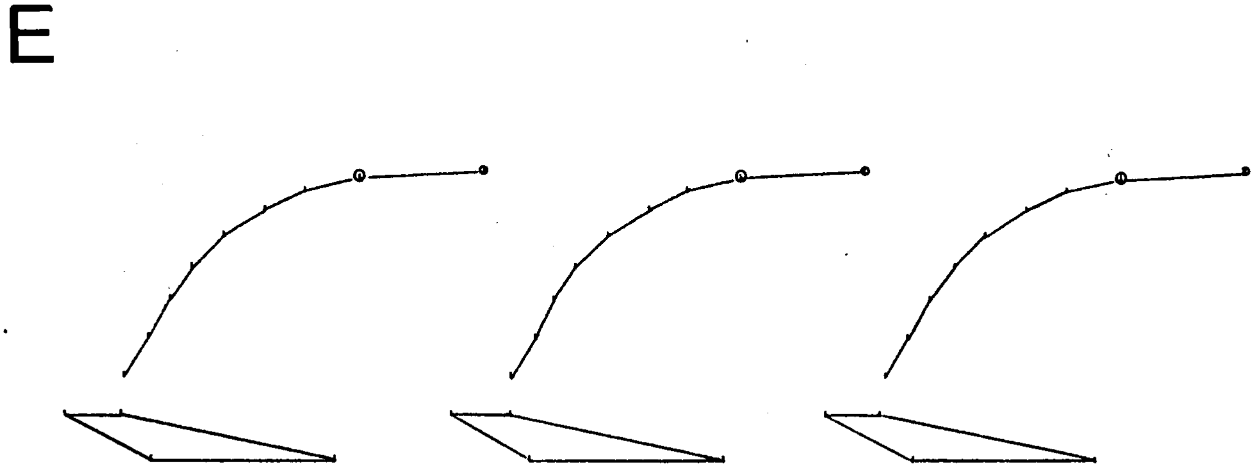


C - Task distance unconstrained, use of foot rail.

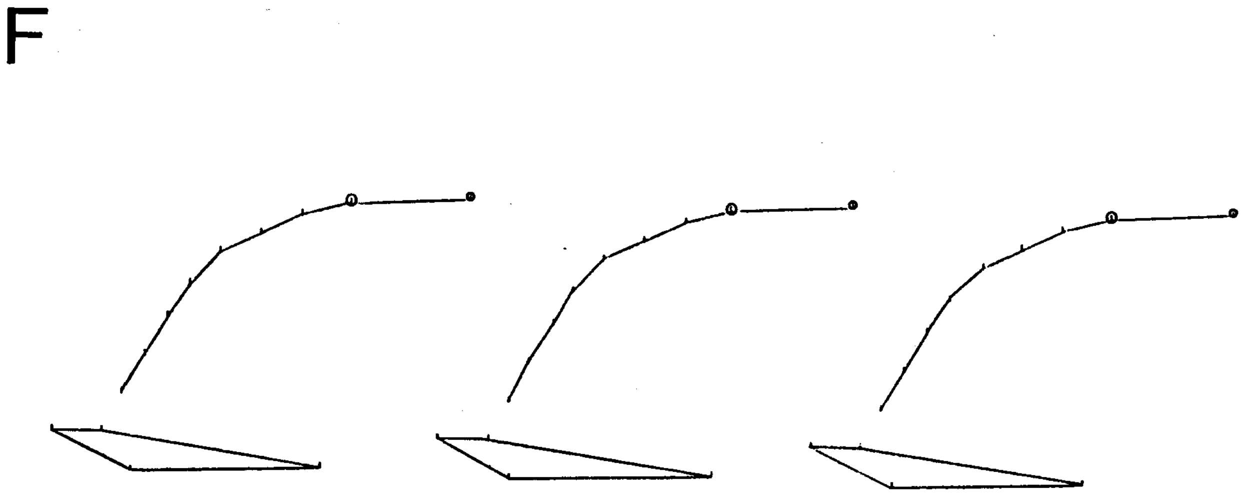
Figure 4.7 Stereo-triplets showing average postural adaptations of back and pelvis for the different workstations.



D - Task distance constrained, unconstrained foot position.



E - Task distance constrained, constrained foot position.



F - Task distance constrained, use of foot rail.

Foot position:

The results of this study confirm the claim made 80 years ago (Mosher 1913, 1914, 1919 in Zacharkow, 1988) that standing posture is largely dependent on foot position. The constrained foot position resulted in more hip flexion than the unconstrained foot position. With the constrained foot position, the front of the subject's foot could not go under the bench, forcing the subject to stand further back and to compensate by increased flexion at the hips.

The constrained foot position also resulted in increased plantar flexion. This could be accounted for by subjects placing their feet as far forward as they could go while increased forward flexion at the hips resulted in a compensatory backward displacement of the pelvis.

Use of the footrail resulted in more trunk flexion, more posterior tilting of the pelvis, less knee flexion in the supporting leg and more plantar flexion in the supporting foot. Posterior pelvic tilt is recommended by clinicians as a means of decreasing lumbar lordosis voluntarily as a person stands and investigators have confirmed that tilting the pelvis posteriorly does decrease the depth of the lumbar curve (Bridger et al, 1992, Day et al, 1984).

Clinicians (e.g. White and Panjabi, 1978) also recommend the use of a footrest for standing workers as it will remove stress from the intravertebral discs and straighten the lumbar curvature. The results of this study show that use of the footrail for both the unconstrained and constrained task distances resulted in a significant increase in posterior pelvic tilt which can be assumed to be accompanied by some decrease of the lumbar lordosis. Day et al (1984) also found that the flexed leg position tended to flatten the lordotic curve in standing.

Increased trunk flexion with use of the footrail is directly linked with increased posterior pelvic tilt as there was no significant increase in trunk inclination. Trunk flexion takes the posture towards the outer range of motion and is associated with increased intradiscal pressure (Nachemson, 1976). Although there was some posterior pelvic tilt coupled with reduced lordosis, the high load imposed by forward flexion may explain in part why the position was not perceived as significantly more comfortable.

Discomfort in this position may also be explained by the overall posture being more flexed on one side than the other, resulting in an asymmetric stance. A close look at the stereo-triplets for workstations C and E shows that the plane of the pelvis tilts down towards the flexed leg on the left.

The areas of discomfort most frequently indicated for workstations C and E were the supporting thigh and leg. Although these positions did result in some posterior pelvic tilt (and decreased lordosis), it is likely that the inherent asymmetry of this position caused discomfort.

Reduced knee flexion in the supporting leg can be assumed to be a result of locking the knee for added stability and the additional weight borne by the leg.There was significantly more plantar flexion in the supporting leg with use of the footrail. With the other foot positions, subjects employed more trunk and hip flexion to enable them to work on the bench. Use of the footrail resulted in the subjects leaning forward from the ankle in order to position themselves over the task.

Further investigations into the use of the footrail may benefit from varying both the position of the footrail and the task distance in an attempt to find a position which will preclude excessive forward flexion and severe asymmetry while still reducing lordosis and increasing perceived comfort. In addition, the results of this study suggest that the frequency of alternating feet on the footrail should also be controlled in order to establish if there is an optimal shifting frequency associated with reduced discomfort.

4.5 Conclusions

Sex was not found to have any significant effect on postural adaptations in standing workers. However, significant postural adaptations to task distance took place in the flexion and inclination of the trunk (with subjects using the lumbar region as a false joint), in the hip joints and in the neck.

Adaptations to constraints on foot position took place in the flexion of the trunk, in the inclination of the pelvis, in the hip joints, the knees and the ankles.

While constrained task distance resulted in less neck flexion, it required more trunk flexion, more pelvic inclination and more hip flexion. This suggests that an optimal task distance should be a compromise between the two task distances, reducing neck flexion and thoracic kyphosis while at the same time reducing trunk and hip flexion.

Constrained foot position, i.e. use of the constraint board, resulted in increased hip flexion but no significant increase in trunk flexion. Increased hip flexion was accompanied by increased plantar flexion.

Use of the footrail did not reduce trunk flexion or increase perceived comfort despite the recommendations of this as a good working position. Instead, trunk flexion was found to increase with use of the footrail and this position was not perceived as significantly more comfortable.

This study confirms that there is a very significant relationship between foot position as influenced by the space made available for the feet and postural adaptations in standing workers. There is no doubt that further research into this relationship will be beneficial and result in some useful guidelines for the design of workspace for standing workers.

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5 - BIOMECHANICAL FORCES ACTING ON THE SPINE DURING FORWARD INCLINATION

5.1 Introduction

When the trunk is inclined forward, the muscular activity of the hip extensor muscles and the back extensor muscles is proportional to the horizontal distance between the hip and lumbosacral joints and the centre of gravity of the upper body. (See **Figure 5.1**.)

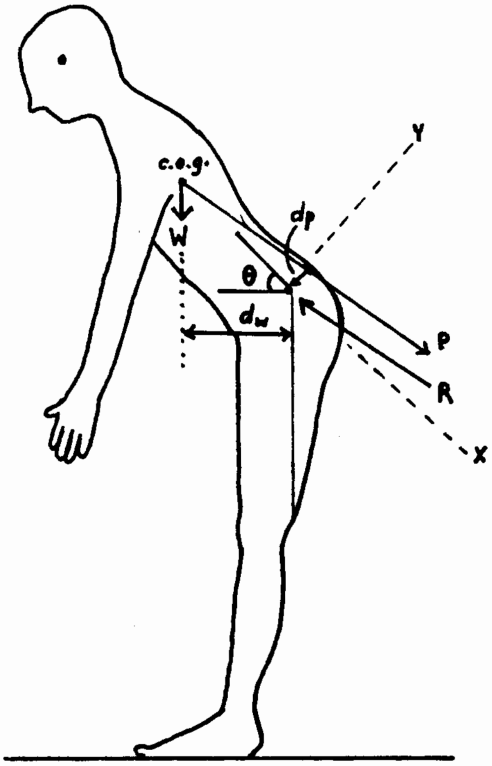

Figure 5.1. Forces on the lower back while bending forward.

P = the tension in the back muscles (erectores spinae)

W = the weight of the head, arms and trunk

d_w = the distance of W from the fulcrum

d_p = the distance of P from the fulcrum (distance between the hip and lumbosacral joints)

R_x = the compressive force acting along the lumbar spine

R_y = the shearing force on the sacrum

(Pheasant, 1986; Nwuba and Kaul, 1986)

The intervertebral disc

The intervertebral disc constitutes 20-33% of the entire height of the vertebral column. It is composed of the nucleus pulposus surrounded by the annulus fibrosus (made of concentric laminated bands of annular fibres) and has cartilagenous end-plates. Sufficient loading and deformation of the disc will lead to herniation, possibly as a result of cumulative damage and disc degeneration. (White and Panjabi, 1978; Pheasant, 1986)

Compression Force

The compressive load is transferred from one vertical end-plate to the other by way of the nucleus pulposus and the annulus fibrosus. (White and Panjabi, 1978)

Shearing Force

The shear force acts in the horizontal plane, perpendicular to the long axis of the spine. It produces shear stresses that are about equal in magnitude over the whole annulus. (White and Panjabi, 1978)

When the trunk is bent forward, the spine is subjected to compressive forces on its concave side and tension on its convex side. In flexion, therefore, the disc bulges anteriorly and is depressed posteriorly. Compression loading of the disc does not produce disc herniation on its own. The tendency for the disc to herniate posterolaterally is considered to be due to the bending and torsional loads on the disc and not to its inherent structure. (White and Panjabi, 1978)

This study used the data available from the previous study on postural adaptations to standing work to explore what the potential compression and shear forces acting on the lumbar spine would be for the various workspaces. The data were examined to determine whether there were significant differences between these forces for the different workspaces, and, if so, what the magnitude of these differences were.

5.2 Method

The formulae used to calculate these forces were adapted from Nwuba and Kaul (1986) :

Spinal extensor muscle force	$\mathbf{P = W * d_w/d_p}$
Forces horizontal to the spinal axis	$\mathbf{P_y = P \sin 8°}$
	$\mathbf{W_y = W \cos \theta}$
Forces along the spinal axis	$\mathbf{P_x = P \cos 8°}$
	$\mathbf{W_x = W \sin \theta}$
Compression on the lumbar vertebrae	$\mathbf{R_x = W_x + P_x}$
Shearing force on the sacrum	$\mathbf{R_y = W_y - P_y}$
Distance of **W** from the fulcrum	$\mathbf{d_w = d_{cog} \cos \theta}$

θ was calculated by taking the angle formed by a line between the head marker and the iliac crest marker, and t[illegible]rizontal through the iliac crest marker respectively.

W was taken as composing 55.2% of body weight (head and neck 8.4%, thoracic segment 21.9%, lumbar segment 14.7% and arms 10.2% - from Chaffin and Anderson (1984)). Exact body weights for the subjects were not known. Body weights were assigned to subjects based on the "ideal" weight for their height. (Williams, 1989)

$\mathbf{d_{cog}}$ the distance from the fulcrum to the centre of gravity of the upper body was based on distances to segment mass centres given in Chaffin and Anderson (1984). It was taken to be .190H, where H is the height of the subject.

$\mathbf{d_p}$ the distance from **P** to the fulcrum, was assumed to be 5cm. (Chaffin and Anderson, 1984)

5.3 Results

Table 5.1. The mean calculated values for all eighteen subjects.

	Task distance unconstrained			Task distance constrained		
	Feet Unconstrained	Feet Constrained	Use of Footrail	Feet Unconstrained	Feet Constrained	Use of Footrail
Shear force R_x (N)	.634	.588	.758	1.433	1.541	1.523
Compression force R_y (N)	83.218	84.690	97.417	135.586	146.780	145.585
Back muscle tension (P) (N)	48.531	50.041	63.552	104.151	116.437	115.136
Distance (cm) to W d_w	6.517	6.606	8.428	14.228	15.783	15.589

Table 5.2. F Ratios from the analysis (by ANOVA) of the effects of Task Distance **(A)** and Foot Position **(B)** on the postural stress variables.

Factor	df	Shearing force	Compression force	Back muscle tension	Distance to W d_w
A	1	** 451.172	** 236.897	** 236.738	** 278.979
B	2	.109	* 3.937	* 3.989	* 3.873
AXB	2	2.137	1.370	1.382	1.573

** statistically significant at the 0.01 level

* statistically significant at the 0.05 level

5.4 Discussion

From **Table 5.2** it is clear that task distance has the most significant effect on all the variables. When task distance becomes constrained (i.e. further away from the subject), the trunk is inclined further forward to bring the hands and eyes closer to the task. **Table 5.1** shows that d_W, , the distance to *W,* increases when the task distance increases. As a result, the shear and compression forces increase with compensating spinal extensor muscle tension.

Foot position also has a significant (but lesser) effect on all the variables except the shear force. While it is not possible to establish any definitive relationship between foot position and postural stress based on these results, it appears that when task distance is *unconstrained*, the postural adaptations to the footrail result in increased compression force along the spine, increased muscle tension and an increase in in the distance to *W*, d_W. When task distance is *constrained*, it is the constrained foot position that appears to result in increases in these variables.

5.5 Conclusion

This exercise serves to illustrate the extent to which trunk inclination can place stress on the lumbar spine and the lumbosacral joint. This ties in with the findings of Nachemson (1976) that standing with 20° flexion can increase intradiscal pressure by 50% and strongly suggests that prolonged forward leaning during standing should be avoided. Based on these calculations, use of a footrest to relieve postural stress in standing workers may not achieve the desired effect.

5.6 References

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6 - POSTURAL ADAPTATIONS TO STANDING VDT WORK

6.1 Introduction

The use of video display terminals (VDTs) has increased dramatically over the past decade and is projected to increase. Much concern has been raised about the possible adverse health effects of VDT use, particularly pertaining to vision, musculoskeletal discomfort and headaches (Bergqvist, 1984; Ong, 1991; Rossignol et al., 1987).

The nature of VDT work has inherent risk factors for musculoskeletal disorders - repetitive actions, strained or confined work postures and static muscle activity due to prolonged immobilisation. A clear relationship between musculoskeletal discomfort and workstation design variables was established by Sauter et al. (1991). Workstation design is considered a key factor in the relationship between VDTs and health (Grandjean et al., 1982; Noro, 1992; Starr et al. 1985).

However there is a lack of consensus about prescribed VDT workstation parameters and "ideal" VDT working postures (de Wall et al., 1992) and a more comprehensive approach to the prevention of these problems is urged (Ong, 1991; Pascarelli and Kella, 1993).

Improved workstation design remains an important factor in preventing musculoskeletal problems. Due to the nature of their jobs, many workers like hotel reception clerks and librarians operate VDTs in a standing position. While the pattern of VDT interaction may be less intense and sustained for these workers than for seated VDT workers, it is nevertheless important to establish design guidelines for standing VDT work. Available research focuses on the seated VDT worker and there is very little data available on the standing VDT worker. The aim of this study is to provide some data on users' adaptations to standing VDT work with particular emphasis on posture.

It was hypothesised that postural stress in standing VDT workers could be exacerbated by design deficiencies in the workplace. A laboratory investigation was conducted to examine standing posture under two degrees of foot constraint with three screen heights. This study also examined the effect of working under these constraints on subjective comfort ratings, performance scores and postural sway.

It has been found that people will adopt an asymmetrical standing attitude four times as often as a symmetrical stance (Smith, 1953). In asymmetrical standing the body weight is supported almost entirely on one limb while the other assists in maintaining balance. Research into seated VDT use has demonstrated asymmetry in working postures. De Wall et al. (1992) found that CAD/CAM workers held their heads to the left rather than the right. Sauter et al. (1991) reported a prevalence of right shoulder, wrist and hand discomfort in VDT users. In the light of this, this study also investigates whether postural adaptations to standing VDT work are asymmetrical.

6.2 Method

a) Posture Measurement

This investigation used the same low-cost PC-based near real-time stereo-photogrammetric system to study the posture of standing workers in three dimensions that was used in the initial study (see **4 - Postural adaptations to workbench modifications in standing workers**).

b) Subjects

Nine healthy male and four healthy female subjects participated in the experiment. The mean age of the subjects was 27.7 years (sd = 5.85). The mean stature of the subjects was 176.4 cm (sd = 8.79).

c) ***Apparatus***

The computerised system was based on that used in the earlier study. It consisted of a video cassette recorder, a two-channel image mixer, two CCD cameras with zoom lenses and a PC with an image processing card.

d) ***Procedure***

Semi-nude subjects who had been standing for 30 minutes were prepared by sticking flat reflective markers on the tips of seven spinous processes including vertebra prominens. In addition, stalks approximately 25cm long with a reflective sphere at the end and midway were mounted over both anterior superior iliac spines (ASIS), both greater trochanters, both knee joints, both ankle joints and both little toes. A similar stalk was mounted on the right of the head at approximately eye level.

In order to test the hypotheses that foot position and monitor height influence standing posture, the subjects were videotaped from the back as they worked at a VDT which was on a bench adjusted for each subject so that the work surface was just below elbow height. Subjects worked with foot position constrained by a board so that their feet could not be placed under the workbench, or unconstrained. The middle of the screen height was either 270mm, 485mm or 700mm above the work surface. 270mm was the height of the screen when placed directly on the work surface, 485mm was considered to be close to eye level for most subjects and 700mm was an equal distance higher. The keyboard remained on the work surface for all configurations.

This gave six different experimental conditions under which the subjects worked, in random order, for five minutes each:

A - Feet unconstrained, screen centre at 270mm (low).

B - Feet unconstrained, screen centre at 485mm (middle).

C - Feet unconstrained, screen centre at 700mm (high).

D - Feet constrained, screen centre at 270mm (low).

E - Feet constrained, screen centre at 485mm (middle).

F - Feet constrained, screen centre at 700mm (high).

Figure 6.1 shows a subject working under the six different experimental conditions.

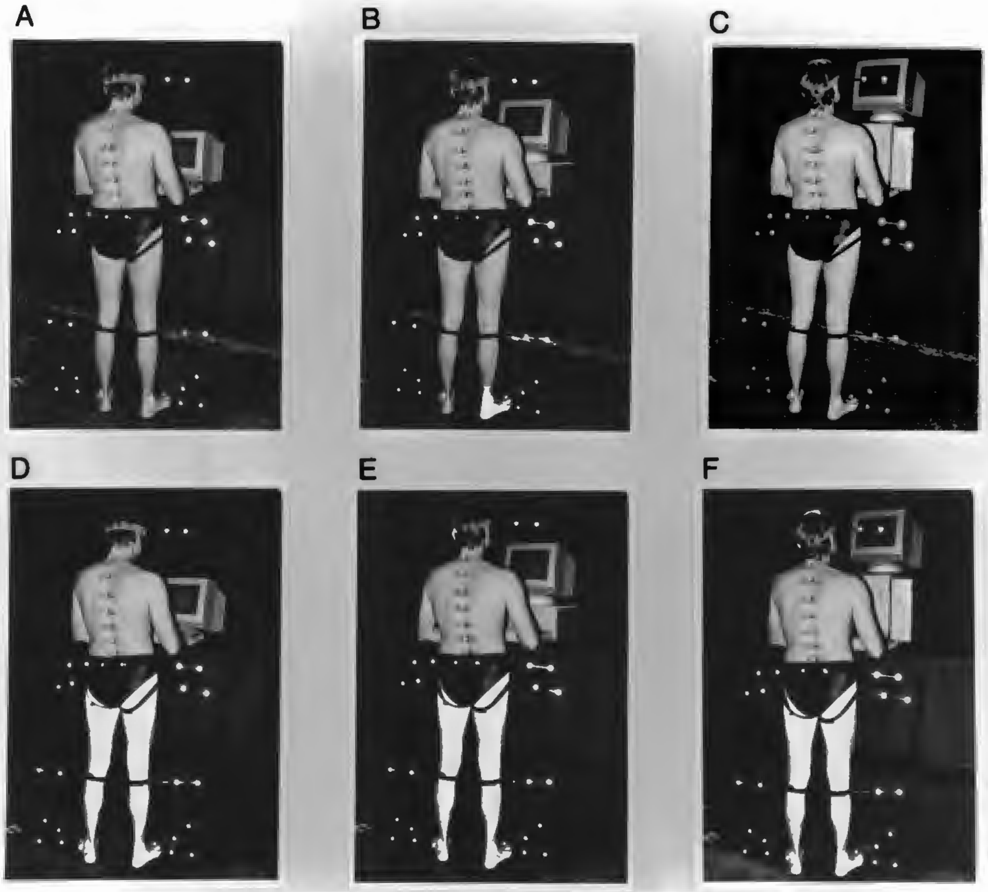


Figure 6.1. ***Subject at work under the six different experimental conditions.***

The subject worked under each experimental condition at a test originally used to demonstrate certain principles of visual perception based on the use of a tachistoscope. A series of nine letters was flashed onto the screen for 500 milliseconds after which the subject attempted to type in all nine correctly. The subjects were encouraged to attempt as many trials as possible and after each five minute session, they received a score of percentage correct and a report on number of trials attempted. The purpose of the test was two-fold. It served as a "secondary task" to absorb subjects and make them less conscious of assuming various standing postures, and the scores obtained could provide an indication of whether the design constraints affected performance and whether performance was linked to subjective comfort.

After working under each experimental condition, subjects were asked to rate the workspace on a scale of one to seven. They were told that one represented the absence of any discomfort and seven represented extreme discomfort or pain which might require urgent rest or even medication (Bridger, 1988). Subjects were also asked to indicate up to three body zones where any discomfort was detected while working under each set of constraints. The zones were : neck, upper back, mid back, lower back, shoulders, upper arms, lower arms, buttocks, thighs and legs. (See **Figure 2.2**, page 54)

e) Observation and mathematical procedures

The images to be measured were selected by viewing the split screen video and were captured on the PC equipped with the image processing card. Only images of working postures were selected and selections were made at approximately 60 second intervals. Each image was then digitised so that the two-dimensional co-ordinates of image points on both the left and the right side were known. A computer program was then run using the two-dimensional co-ordinates of the fiducial marks and a two-dimensional linear transformation to correct for shift of the video frames due to the pause function of the video machine. This same software then derived the three dimensional co-ordinates of the points on the body by a method of projective transformation as discussed by Adams (1981).

The position of the base of each stalk was calculated using the co-ordinates of the two spheres and the distance between them.

f) Presentation of results

A further computer program was run to derive postural angles using the relevant spatial co-ordinates. The program calculated seven average postural angles for each subject under each of the six experimental conditions. With the exception of neck flexion, postural angles were also determined for the left and right side of the body. The seven postural angles are illustrated in **Figure 6.2**.

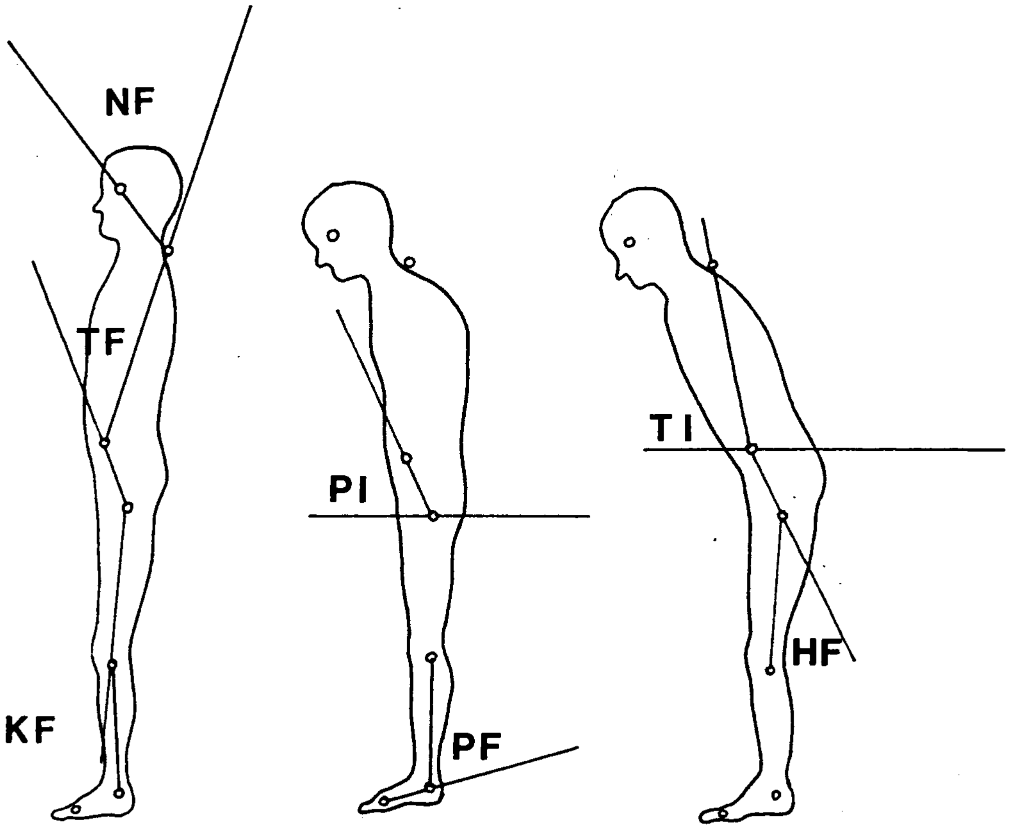


Figure 6.2. ***Anatomical location of markers used to derive the seven postural angles. (NF - Neck Flexion, TF - Trunk Flexion, HF - Hip Flexion, TI - Trunk Inclination, PI - Pelvic Inclination, KF - Knee Flexion, PF - Plantar Flexion)*** **Because of a different system of body markers, TI and PI are not the same as in the previous study.**

The seven postural angles are fully defined in the previous study (**4 - Postural adaptations to workbench modifications in standing workers)** although it must be noted that in this study pelvic inclination and trunk inclination increase as the associated angles grow smaller.

g) Postural Sway

Four of the original subjects were videotaped for a five minute period while they stood as still as possible. Automatic digitising software determined the three-dimensional co-ordinates in space every second (approximately 180 times) of a marker on vertebra prominens over the central three minutes. This was compared with corresponding co-ordinates from a three minute section of the subject's original VDT session when he or she worked under condition B (feet unconstrained, screen at middle height).

6.3 Results

Effects of workstation factors on postural variables

For each of the seven postural variables, the data were treated as a mixed 2 X 2 X 3 repeated measures design of two fixed factors with subjects as a third (random) factor and five observations per cell. The experimental factors were screen height (3 levels), foot constraint (2 levels) and side (left or right).

Tables 6.1(a) and **6.1(b)** present the grand means for each constraint/variable combination over all subjects for the left and right sides respectively. **Table 6.2** presents the results for ANOVA for the comparisons between these means.

Table 6.1(a) - (Left Side)

Means and standard deviations (sd) of postural angles (in deg) for the six design constraints

	FEET UNCONSTRAINED			FEET CONSTRAINED		
Postural Variable	SCREEN LOW	SCREEN MIDDLE	SCREEN HIGH	SCREEN LOW	SCREEN MIDDLE	SCREEN HIGH
TF						
mean	38.76	38.96	40.09	39.96	39.91	39.91
sd	8.75	9.08	10.17	8.77	8.29	9.40
HF						
mean	25.37	26.24	25.91	25.61	27.12	26.18
sd	8.51	9.27	9.14	8.75	7.74	10.10
PI						
mean	70.44	70.36	69.39	69.49	68.44	69.4
sd	7.68	7.79	8.75	8.14	7.01	8.59
TI						
mean	108.57	108.66	108.78	108.77	107.68	108.65
sd	3.33	3.33	2.63	3.06	4.05	3.48
NF						
mean	-	-	-	-	-	-
sd						
KF						
mean	7.03	6.84	7.27	7.74	7.61	8.38
sd	3.88	2.76	4.16	4.37	5.52	3.92
PF						
mean	72.51	72.70	71.46	71.86	75.05	71.92
sd	5.00	5.95	5.78	5.24	9.17	4.31

Table 6.1(b) - (Right Side)

Means and standard deviations (sd) of postural angles (in deg) for the six design constraints

	FEET UNCONSTRAINED			FEET CONSTRAINED		
Postural Variable	SCREEN LOW	SCREEN MIDDLE	SCREEN HIGH	SCREEN LOW	SCREEN MIDDLE	SCREEN HIGH
TF						
mean	37.40	36.98	39.24	39.61	39.58	38.3
sd	8.05	7.59	9.96	9.94	10.39	8.27
HF						
mean	23.79	25.06	27.03	25.73	26.66	26.31
sd	6.54	7.79	8.08	6.92	7.27	8.55
PI						
mean	67.99	68.40	66.60	66.41	66.42	66.94
sd	7.41	7.56	8.32	9.01	8.77	7.52
TI						
mean	104.19	104.20	104.26	104.87	102.98	103.89
sd	3.61	3.78	3.52	3.06	4.83	3.84
NF						
mean	82.11	75.77	70.86	81.68	77.30	71.15
sd	6.94	5.60	5.26	6.11	6.12	6.46
KF						
mean	6.26	6.84	7.82	8.05	8.22	7.17
sd	3.86	3.63	5.96	5.64	5.05	4.32
PF						
mean	71.07	71.09	70.52	71.48	72.07	70.38
sd	4.44	3.67	3.42	4.83	3.22	5.24

Table 6.2. F Ratios from the analysis (by ANOVA) on the effects of Side (Left or Right) (A), Foot Position (B) and Screen Height (C) on the seven postural variables.

		POSTURAL VARIABLE						
Factor	**df**	**TF**	**HF**	**PI**	**TI**	**NF**	**KF**	**PF**
A	1	9.27**	1.28	72.45**	1215.95**		.06	22.17**
B	1	7.59**	6.57*	12.09**	5.66**	1.64	5.69*	3.20
C	2	0.86	8.43	1.00	11.23**	117.42**	0.42	9.36**
AXB	1	0.79	0.73	0.05	0.00		0.00	0.23
AXC	2	0.11	2.90	0.69	1.56		0.30	1.76
BXC	2	4.68**	2.90	4.74*	12.06**	1.19	0.79	3.11
AXBXC	2	1.04	2.07	0.23	0.89		1.50	1.29

These results show that posture was significantly asymmetrical. Factor A (Side) significantly affected trunk flexion (TF), pelvic inclination (PI), trunk inclination (TI) and plantar flexion (PF). Comparing **Table 6.1(a)** to **Table 6.1(b)** shows that the trunk was more flexed on the right than on the left, the trunk was more anteriorly inclined on the right than on the left, the pelvis was more anteriorly inclined on the right than on the left, and there was significantly more plantar flexion on the right than on the left.

Factor B (Foot Position) had a significant effect on trunk flexion (TF), hip flexion (HF), pelvic inclination (PI), trunk inclination (TI) and knee flexion (KF). Examination of **Tables 6.1(a)** and **(b)** show that for both sides, with the feet constrained (for the low and middle screen heights) the trunk was less flexed and the pelvis more anteriorly tilted. In addition, the constrained foot position resulted in more hip flexion, greater forward inclination of the trunk and more knee flexion.

Factor C (Screen Height) had a significant effect on neck flexion, hip flexion, trunk inclination and plantar flexion. The neck was more flexed as the screen was lowered. The hips were more flexed as the screen was raised. For the constrained foot position there was significantly more anterior trunk inclination for the middle screen height than for the low and high positions.

There was significant interaction between foot position and screen height for the postural variables trunk flexion, pelvic inclination and trunk inclination.

Comfort

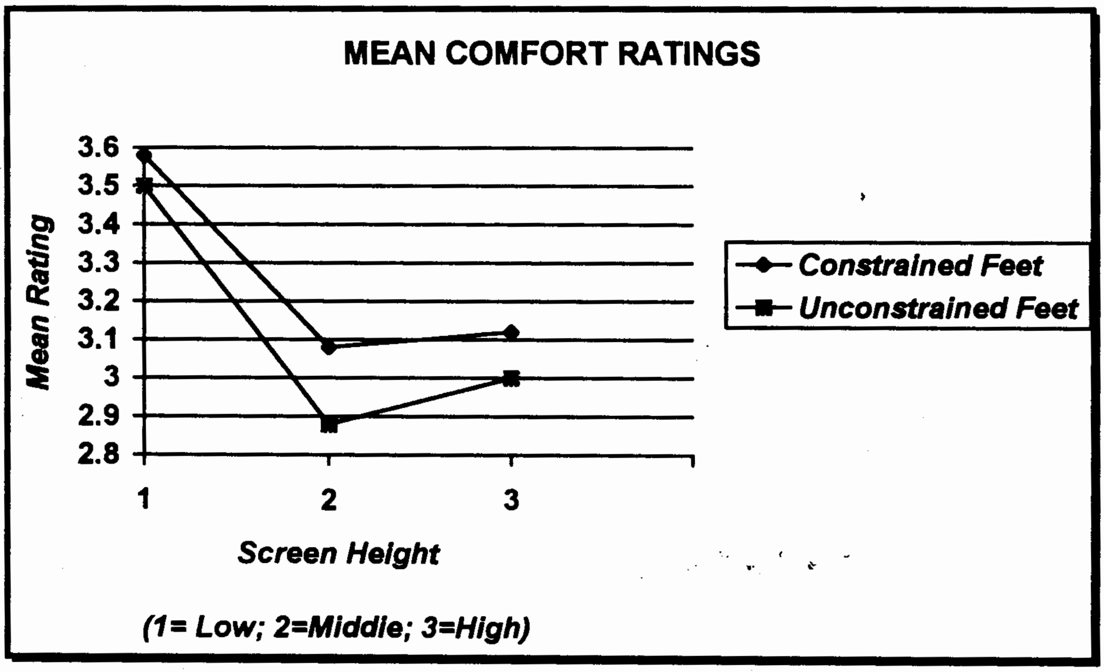
Subjects rated the workspaces on a seven-point scale (1 = very comfortable, 7 = extremely uncomfortable). **Table 6.3** summarises the mean comfort rating of the work spaces.

Table 6.3. Mean comfort ratings for the six workspaces

	FEET UNCONSTRAINED			**FEET CONSTRAINED**		
	SCREEN LOW	**SCREEN MIDDLE**	**SCREEN HIGH**	**SCREEN LOW**	**SCREEN MIDDLE**	**SCREEN HIGH**
Comfort Mean	3.50	2.88	3.00	3.58	3.08	3.12

These results are presented graphically below.

Figure 6.3 Mean comfort ratings for the six workspaces



The comfort ratings were analysed using Friedman's two-way ANOVA by ranks, which yielded the result Chi-square = 5.0, df = 5, p = 0.4159. There was therefore no significant relationship between subjective comfort rating and workspace constraints although it is clear from **Table 6.3** that discomfort was highest for the low screen height and lowest for the middle screen height.

The results were also analysed using Page's 'L' test to determine whether subjects felt more uncomfortable the longer they worked (Page, 1963). This was found to be the case (L = 21.1, m = 6, n = 13, p = 0.01). Thus the time spent standing seems to be a more powerful determinant of comfort than workstation design over the one hour periods of standing observed in this study. This is illustrated in the following graph.

Figure 6.4 Mean comfort rating over time

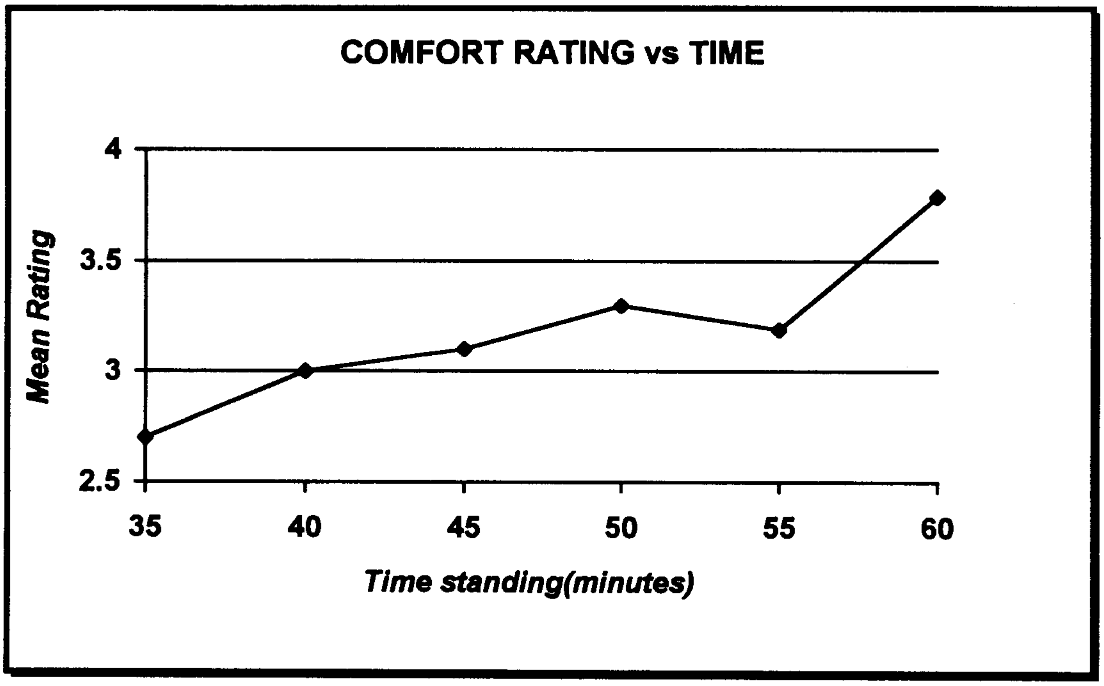


Table 6.4 indicates the areas of discomfort most frequently indicated for each of the experimental constraints. *(Note that "area of discomfort" refers to the body zone where discomfort is perceived while "comfort rating" refers to the overall comfort or lack of comfort experienced by the subject. "Comfort rating" could be refered to as "discomfort rating" without any loss of meaning.)*

Table 6.4 Most frequently reported body zones.

(See above for definition of constraints)

CONSTRAINT	FREQUENCY (%)	ZONE OF DISCOMFORT
A	33	Legs
B	50	Legs
C	37.5	Legs and lower back
D	29.4	Legs, lower back & neck
E	45.5	Legs
F	36.4	Legs

Legs were most frequently indicated as a discomfort zone under all six sets of constraints.

Test scores

Percentages achieved (accuracy) for each set of trials were multiplied by the number of trials attempted in order to normalise the scores. **Table 6.5** summarises the scores achieved for the six workplaces.

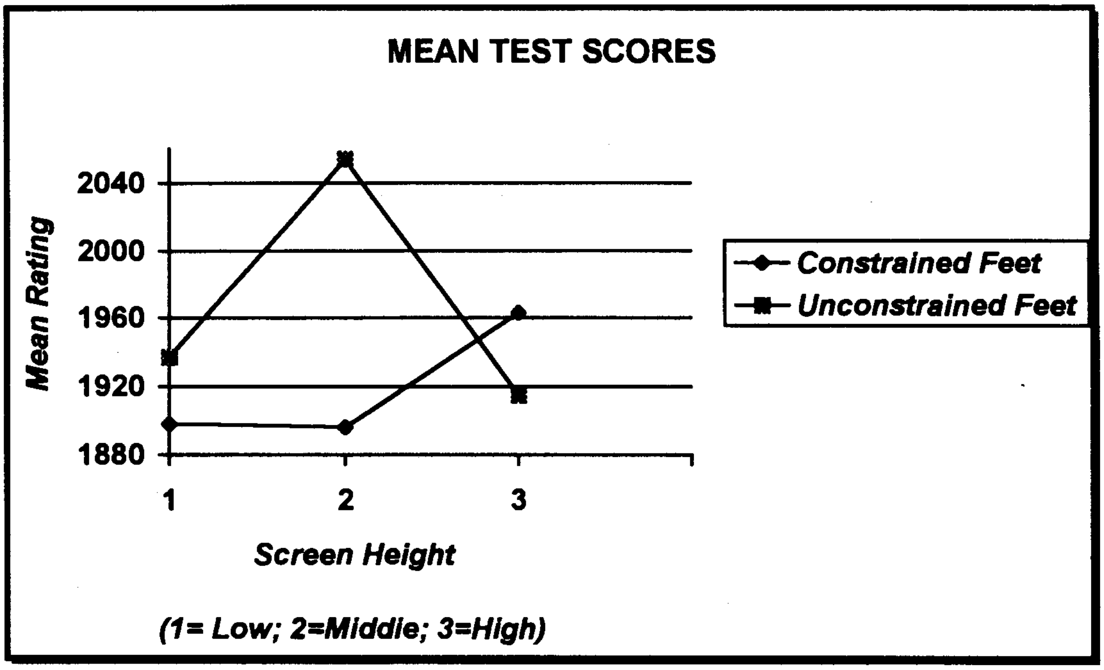
Table 6.5. Mean Test scores for the six workspaces.

	FEET UNCONSTRAINED			FEET CONSTRAINED		
	SCREEN LOW	SCREEN MIDDLE	SCREEN HIGH	SCREEN LOW	SCREEN MIDDLE	SCREEN HIGH
Test score	1937	2054	1915	1898	1896	1963

(Test score = number of trials attempted X average percentage corrected)

These results were analysed by ANOVA and it was found that screen height had a significant effect on accuracy (F-ratio = 3.86, $p < 0.05$, df = 2). Examination of **Table 6.5** and the graph below shows that, for the unconstrained foot position, scores were higher for the middle screen position.

Figure 6.5 Mean test scores for different workspaces



Postural sway

Table 6.6 gives the mean and standard deviation displacements of the body in the X (perpendicular to the plane of the screen) and Z (parallel to the plane of the screen) dimensions.

Table 6.6 F Ratios from the analysis (by ANOVA) of the effects of Foot Position (A) and Screen Height (B) on performance.

Factor	df	F-Ratio	significance level
A	1	.605	.4526
B	2	3.168	.0601
A X B	2	1.743	.1964

Greater body movement was observed in the direction of the screen when working at the VDT than when standing relaxed (23.3mm versus 62.2mm, $t = 2.79$, $p < 0.05$, $df = 4$). There was no significant difference in lateral movement however (14.9mm versus 20.3mm, $t = 0.66$, $p < 0.05$, $df = 4$). The standard deviations of displacements were also not significantly different (chi-square = 7.64 and 7.39, $p < 0.05$).

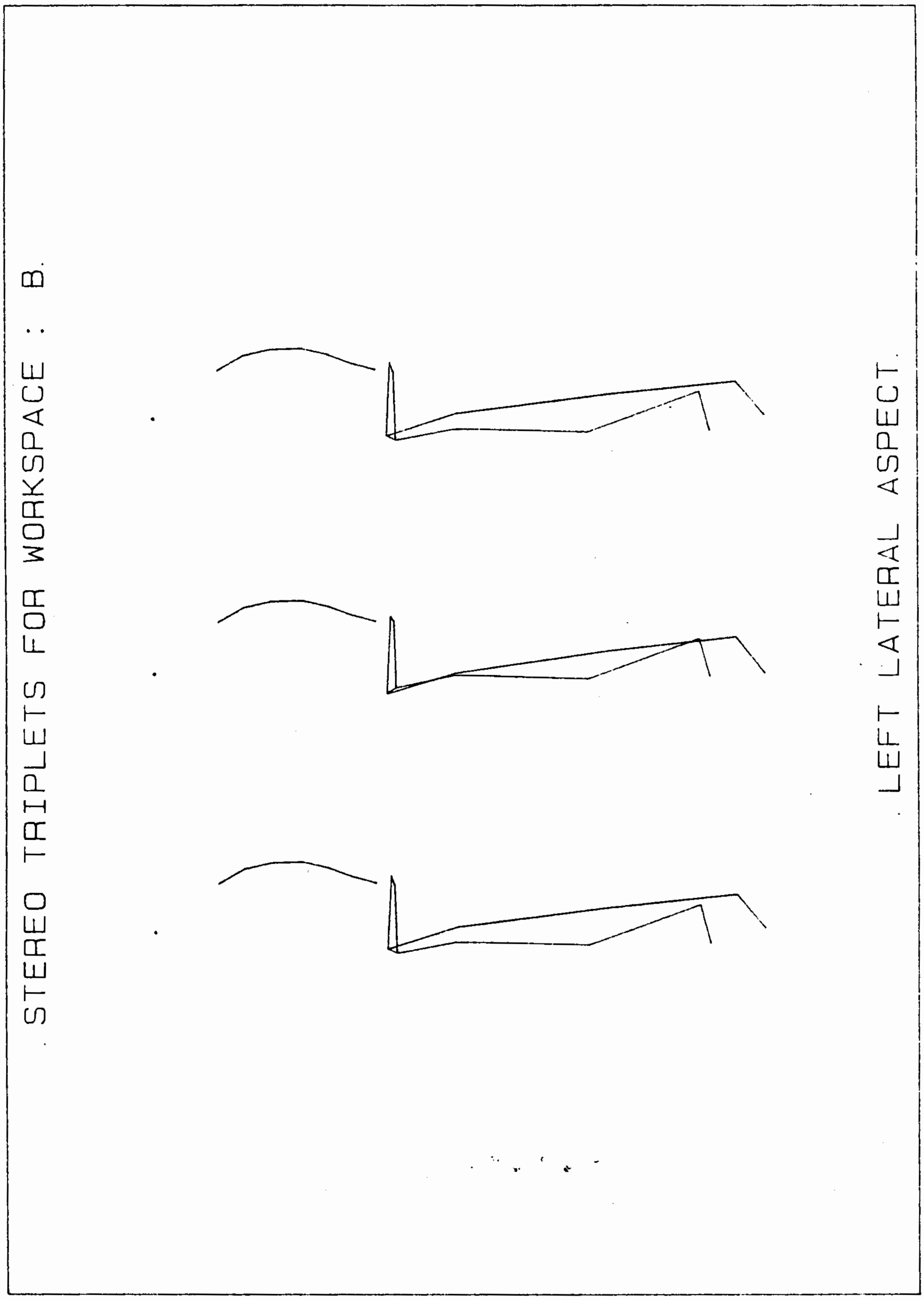
6.4 Discussion

Asymmetry

Smith (1953) found that in standing subjects an asymmetrical posture was adopted four times as often as the symmetrical attitude. In the asymmetrical standing posture, the weight is carried on one foot while the balancing foot is placed antero-laterally. There is more flexion at the ankle, knee and hip on the 'balancing' side than the other side and the pelvis is tilted forward relative to the supporting side. These findings concur with this study where there was significantly more plantar flexion, forward tilting of the pelvis and trunk inclination and flexion on the right hand side. It can be assumed, therefore, that the subjects tended to adopt an asymmetrical attitude and that they preferred to use the left leg as the supporting leg. Smith, however, found no significant difference in the frequency of left or right asymmetrical attitudes.

The stereo-triplet in **Figure 6.6** (following page) illustrates the average stance adopted by subjects while working under experimental condition **B** (feet unconstrained with the middle screen height). This stereo-triplet clearly shows how one leg (the non-supporting leg) is more flexed than the other.

Figure 6.6. The average stance adopted by subjects while working under experimental condition *B*.



Other research into VDT use has demonstrated related asymmetry. DeWall et al. (1992) found that seated CAD/CAM workers held their heads to the left rather than to the right. The prevalence of right shoulder, wrist and hand discomfort reported by Sauter et al (1991) and the findings of the present study may be directly related to a predominance of right-handedness and preferred use of the right hand for keyboard operation.

Foot position

Foot position had a significant effect on all postural variables except neck flexion and plantar flexion. The constrained foot position resulted in a posture with knees slightly flexed, pelvis tilted forward and hips flexed. The trunk remained extended while pelvic tilting caused it to be inclined towards the work surface. In general, the constrained foot position resulted in more bending forward from the hip than the unconstrained foot position. The feet were forced further away in the constrained foot position than in the unconstrained condition. This led to increased flexion at the hips, with a corresponding increase in the flexion moment of the trunk. These adaptations to the constrained foot condition are suggestive of an increased postural load due to the need to counteract torques around the supporting joints.

Screen height

Screen height was found to influence hip flexion, trunk inclination, neck flexion and plantar flexion significantly. In particular, for the unconstrained foot position, hip flexion increased as the screen height increased. This implies that raised screen height resulted in the subjects bending forward at the hip to get closer to the screen. However, there is no accompanying increase in trunk inclination to confirm this explanation.

The effects on trunk inclination, hip flexion and plantar flexion in the constrained foot position appear to be related. All three variables are less for the low and high screen positions and greater for the middle screen position. This suggests that, when the feet are forced further away from the workbench, the middle screen height (which is closest to eye level) resulted in a posture that is more inclined above the hip and moves the weight further forward over the feet than the other screen positions.

Hip flexion increased as the screen was raised except for the high screen setting with the feet constrained. Conversely, as the screen was raised, neck flexion decreased. This compensation is contrary to the expectation that the hips flex and move backward in order to counterbalance the weight of the head as it goes forward and down. It implies that subjects used hip flexion to move closer to the screen and neck flexion to lose or gain eye height.

Trunk flexion increased significantly for the high screen when the feet were constrained and decreased when the feet were unconstrained. Similarly, pelvic inclination increased significantly for the high screen when the feet were constrained and decreased when the feet were unconstrained. The height of the screen combined with the constraint on foot position forced subjects into a strained posture with the centre of gravity forced away from the axis of rotation of the joints.

Comfort

There was no significant relationship between comfort rating and workspace constraints. However, the figures in **Table 6.3** suggest that they did not prefer the low screen height. Further investigation into this may be useful as it could contradict Heuer's (1993) finding that most (seated) subjects preferred the low VDT position (about minus 35 degrees below the horizontal) and the recommendation that lower VDT screens be used to reduce blinking frequency (Tsubota and Nakamori, 1993). However, it must be emphasised that these findings are for seated VDT work and it may be more comfortable to look down from a seated position than from a standing one.

It was found that subjects reported increased discomfort with time. Discomfort seems to increase fairly steadily over the first 25 minutes of standing work while the last five minutes seem to indicate a more rapid increase in discomfort. This suggests that standing workers should be given rest periods at least every hour. Further research into perceived comfort over time may confirm this view and generate useful guidelines for standing VDT work. The trend indicating increased discomfort over time would account for the absence of significant differences between comfort ratings for different workspaces, since presentation order of different conditions was randomised over subjects.

Subjects experienced discomfort in their legs for all workspaces and it must be assumed that this is directly related to prolonged standing and not due to any other constraints imposed by the workspaces.

Test scores

It was anticipated that some relationship between task performance and comfort rating would be found as research has shown that mentally demanding VDT tasks result in muscle tension (Waersted and Borklund, 1991) and physiological changes due to stress (Gao et al., 1990). Although the effect of duration on perception of comfort obscured any possible relationship between comfort and performance, it was found that screen height affected accuracy. For the constrained foot position, accuracy increased as screen height was raised. For the unconstrained foot position, accuracy was 2.8 percent greater for the middle screen height. Performance was worst when the screen height was low.

Postural sway

Greater body movement in the direction of the screen was observed when subjects were working at the VDT than when standing relaxed. It would appear that operating a VDT in a standing position in a task such as this (when the only visual elements are the keyboard and the screen) is accompanied by a small increase in anterior/posterior displacements of the body. However, apart from this approximate 40mm increase in anterior and posterior movement, the task posture is barely distinguishable from standing still and can therefore be associated with those postural stresses resulting from prolonged static standing.

6.5 Conclusions

This study found that standing subjects working at the VDT predominantly adopted an asymmetrical posture that favoured the use of the left leg as supporting leg. Foot position significantly affected posture. The constrained foot position resulted in subjects bending forward from the hips to be nearer the workbench and the VDT.

Screen height also significantly affected posture. Raised screen height resulted in decreased neck flexion which was compensated by increased hip flexion. When the feet were constrained, the middle screen height resulted in a more strained posture. The low screen height was perceived by subjects to be the least comfortable for both foot positions.

The subjects performed worst (accuracy) when the screen was low. Investigation into postural sway showed that standing VDT work is only slightly less static than standing still in a relaxed position. This study also showed that static standing, even over a short period of time, results in more discomfort in the legs than any other body zone. Discomfort seems to become worse towards the end of an hour's standing.

Recommendations for seated VDT workstation design are not always applicable to standing VDT work. Seated VDT workstation design emphasises the chair (backrest height and seat pan angle, for example). In addition, the findings of this study suggest that other recommendations for seated VDT work such as gaze angle to the VDT centre and keyboard slope and positioning may have to be re-examined for standing VDT work.

6.6 Recommendations

Based on this research, the middle screen setting at approximately eye level (about 500mm above the work surface) results in the least strained posture and should be recommended for standing workers. Where possible, foot position should be unconstrained by providing unobstructed free space for the feet. Standing VDT workers should be made aware of the need to shift the weight from foot to foot while standing in order to minimise soft tissue stress, particularly in the legs. As it has been shown that standing working at the VDT is barely distinguishable from standing still, prolonged standing VDT work should be avoided by alternating this with other tasks and by sitting occasionally, if this is possible.

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7 - EVALUATION OF STANDING AIDS FOR THE WORKPLACE

7.1 Introduction

Workspace design conventionally caters for a limited range of working postures, mainly sitting or standing. Seated workers generally perform tasks that require limited mobility. Confinement to the ubiquitous chair limits the working posture of the seated considerably. The standing worker, although often working within severe space constraints, does not have the added constraint of aligning his body closely to a piece of furniture. However, this does not mean that he may not benefit from the use of other and less conventional furniture.

According to Hewes (1957), the ordinary upright stance is only one of approximately 1,000 different static postures which human beings can assume and maintain comfortably for some time. He suggests that we should explore the possible usefulness of alternate postures when planning workspaces. Some of these postures may involve interaction with an object which helps the person to maintain balance and stability while minimising strain on the soft tissues. An excellent example of this is the long stick used by the Nilotic herdsman. (See Page iii)

Rys and Konz (1989) found that subjects who put one foot forward onto a low platform at regular intervals were more comfortable in all areas of the body, except the upper and lower leg and forefoot, than a group who stood "normally" without performing this action. This forward standing resulted in significantly higher comfort in the neck and heel areas. The approach used by these researchers is extended here in order to evaluate standing aids for the workplace.

In this study, standing aids were used to test the hypothesis that enabling the subject to have some degree of support while remaining in an upright position, would allow him to assume alternate postures which would decrease discomfort during prolonged constrained standing.

7.2 Method

Apparatus

Three standing aids were used in this study:

1. - a two-meter long 30mm diameter wooden pole with a tennis racquet grip.
2. - a padded kneerest of adjustable height. The padded area was 500mm by 250mm and was covered in vinyl.
3. - a footrail with four rails which were 500mm wide and 120mm, 240mm, 360mm and 480mm from the floor.

Figure 7.1. ***Subject standing with the stick.***

Figure 7.2. ***Subject using the padded kneerest.***

Figure 7.3. ***Subject using the footrail.***

Subjects

15 healthy male and 26 healthy female subjects participated in the study. The mean age for the males was 22,1 years, their mean weight was 72,9 kg and their mean height was 175cm. The mean age for the females was 21,1 years, their mean weight was 61,4 kg and their mean height was 160,3 cm. Of the 41 subjects, 36 were right handed (87,8%) and 5 were left handed (12,2%).

Procedure

Subjects were randomly assigned to one of four groups:

- 10 used the footrail
- 10 used the kneerest
- 10 used the stick
- 11 had no standing aid.

The subjects stood barefoot or in socks for eight sessions consisting of 27 minutes of standing and three minutes of rest - total of 240 minutes each. (After Rys & Konz, 1989). During the 27 minute session they were confined to a carpeted area 500mm by 500mm and during the 3 minute break they could walk about or rest comfortably. The kneerest and the footrail were constructed so as to fit directly in front of the 500mm by 500mm square. Subjects were videotaped while they watched popular films on video.

At the end of each 27 minute session, subjects were shown a body diagram (see **Figure 2.2**, page 54) and asked to point out up to 3 zones where they had experienced discomfort and/or pain. They were also asked to rate their overall comfort on a scale of 1 to 7, where 1 represents the total absence of discomfort and 7 represents acute discomfort or pain. (Bridger, 1988)

Observation and data capture

Each videotape was played back and for each session, the number of times the subject made contact with the standing aid, the duration (seconds) of each contact and, in the case of the footrail or kneerest, whether the right or left leg was lifted, were recorded.

7.3 Results

Interaction with standing aid

Table 7.1 shows the total contact time overall for all subjects for each standing aid as well as the percentage of the total time available (129600 seconds).

Table 7.1. *Total contact time overall (seconds)*

Footrail	17371	(13,4%)
Kneerest	34140	(26,3%)
Stick	12122	(9,4%)

There was significantly more contact overall made with the kneerest than with the other two standing aids. (Anova: F = 19,4; p < 0,01) There was also a significantly greater number of contacts made with the kneerest than with the other two aids.(Anova: F = 32,0; p < 0,01) For all subjects, 260 contacts were made with the kneerest, 187 with the footrail and 18 with the stick.

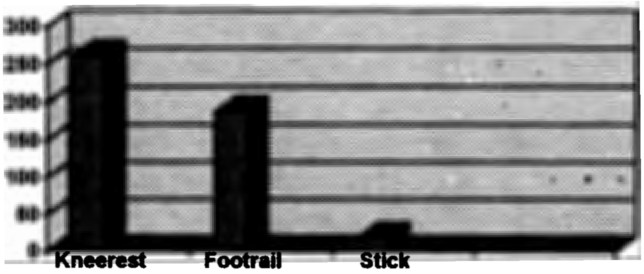

Figure 7.4. *Number of individual contacts made with the standing aids.*

Number of contacts with the stick were considerably lower than the other two aids. However, the different standing aids had a significant effect on mean duration. (Anova: F = 6,6; p <0,01) The mean duration for the stick was 673,4 seconds, for the kneerest 130,2 seconds and for the footrail 92,5 seconds. Contacts with the kneerest were therefore not only more frequent than contacts with the footrail but also of longer duration. Contacts with the stick were very infrequent but considerably longer in duration.

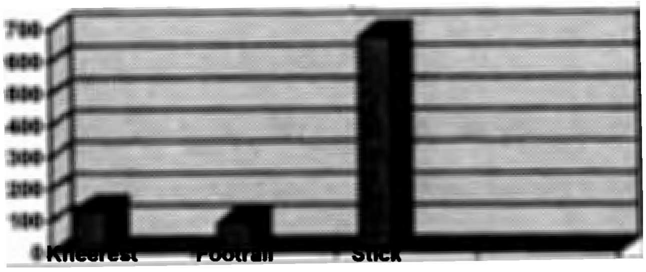

Figure 7.5. ***Mean duration of contacts with the standing aids (seconds).***

Total duration of contacts varied significantly over the eight periods. (Anova: F-statistic - 5,7; significance level < 0,01) **Figure 7.6** shows how, for all standing aids, total contact time increased the longer the subjects stood.

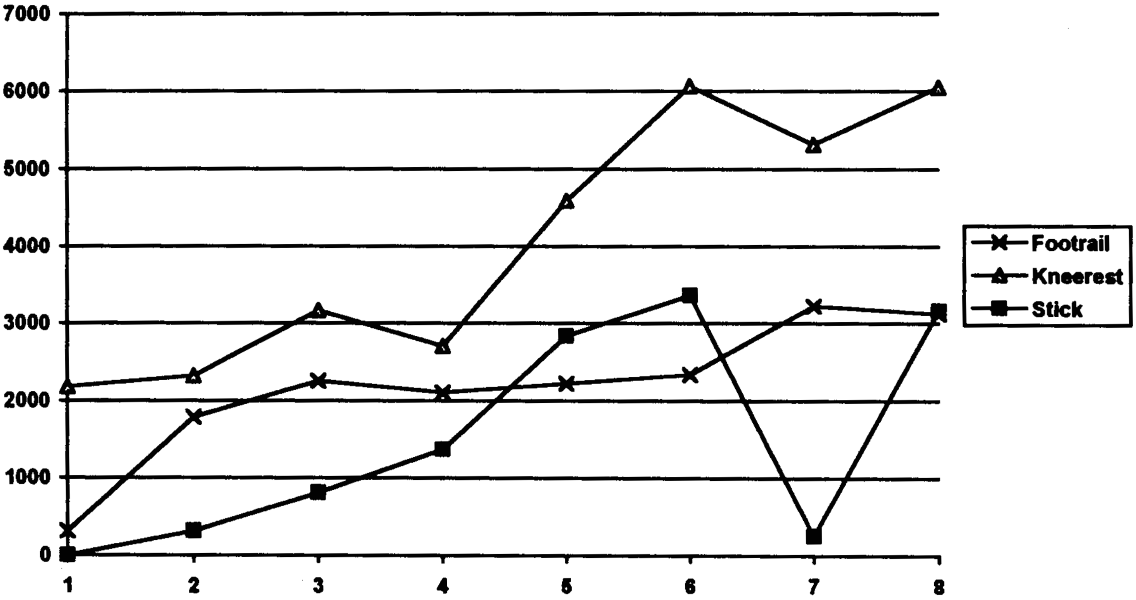

Figure 7.6. ***Total contact time (seconds) over the eight 27 minute periods.***

As mean contact duration did not vary significantly over periods, increased total contact time is explained by the significant variation of number of contacts over the eight 27-minute periods. (Anova: F = 3,2 ; p <0,05)

Figure 7.7 shows how number of contacts with the footrail and kneerest increased over time, particularly in the last two periods. Contacts with the stick remained fairly constant over time.

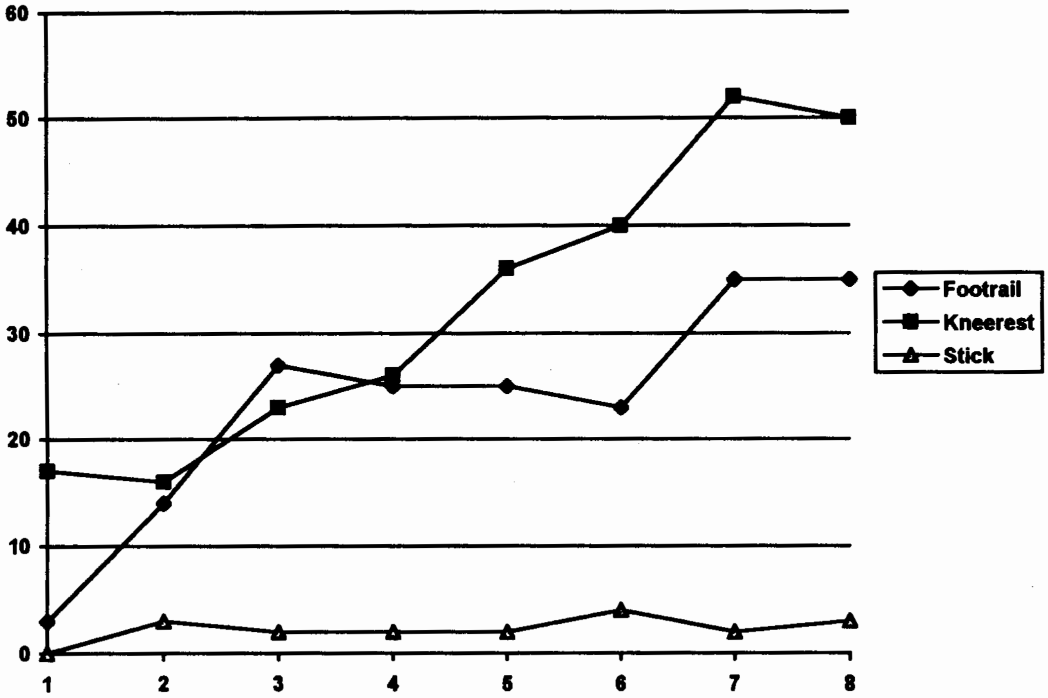

Figure 7.7. ***Number of contacts with standing aids over the eight periods.***

Comfort Rating

Comfort rating differed significantly between the four groups. (Kruskal Wallis Anova: F = 11,13, p < 0,05) **Table 7.2** shows the mean ratings.

Table 7.2. *Mean Comfort Ratings*

Group	Mean Rating
Footrail	3,50
Kneerest	4,18
Stick	3,66
Control	3,80

The group using the kneerest reported greater discomfort than the other three groups. Two-sample analysis showed that there was no significant difference between the control group and the groups using the stick and the kneerest. However, there was a significant difference in discomfort perceived by the group using the footrail and that perceived by the control group (F = -3.07, p < 0.01).

Body Zones

Discomfort was predominantly reported in the lower legs followed closely by the lower back.

Table 7.3. *Percentage of compaints by body zone*

	Footrail	Kneerest	Stick	Control
Legs	43,4%	37,2%	47,7%	43,7%
Lowerback	24,8%	36,6%	36,7%	29,8%
Shoulders	4.4%	6.9%	-	8.0%
Thighs	5.3%	8.3%	1.8%	6.0%
Mid back	4.4%	2.1%	1.8%	4.6%
Buttocks	-	1.4%	0.9%	2.6%
Lower arms	-	-	-	1.3%
Upper back	4.4%	0.7%	2.8%	-
Upper arms	0.0%	2.1%	-	-

On average, legs and lower back accounted for 75% of the body zones indicated while neck, shoulders and thighs accounted for 18,2%.

Preferred Rungs of the Footrail

Results are shown in **Table 7.4.**

Table 7.4 - *Footrail rung preference.*

Rung	Contact (secs)	Percent. total	Contact (number)	Percent. total
1	3578	20,6%	44	23,5%
2	4742	27,4%	56	29,9%
3	5839	33,7%	51	27,3%
4	3170	18,3%	36	19,3%

Subjects moved their feet more frequently onto Rung 2 (240mm above the ground) although they kept their feet longest on Rung 3 (360mm above the ground).

Left and Right side preferences

There was not a significant preference for one side. For the footrail, subjects used their right feet for 58,8% of the contacts and their left feet for 41,2%. For the kneerest subjects used their right legs for 52,7% of the contacts and their left legs for 47,3%.

7.4 Discussion

Contacts with the standing aids increased over time and this was accounted for by the increased number of contacts and not by longer duration of individual contacts. The kneerest had the longest contact time overall. Subjects lifted their legs up to the rest 40% more than subjects lifted their feet onto the footrail.

However, the group using the kneerest reported the greatest discomfort. The results clearly show that use of the stick and the kneerest did not decrease discomfort while use of the footrail did decrease discomfort. In general, the aids seem to have served more as a means of distraction over the long session which would explain why number of contacts increased over time. It is possible that the subjects felt the need to move more over time due to ischaemia or venous pooling in the legs and feet. The kneerest was padded and it is also possible that this, although apparently offering no significant relief, invited more contacts than the footrail.

The results suggest that rung 3 of the footrail (at 360mm above the ground) was more comfortable than the other rungs as subjects used it the longest. However, rung 2 was used more frequently and it is possible that this was because at 240mm from the ground it was nearer and more accessible.

The subjects showed a marked reluctance to use the stick and it is possible that they did not know how to use it the way a Nilotic herdsman might, for example. Ignorance of how any of the stick and kneerest might best be used to alleviate discomfort may account for the fact that they gave no significant relief. Although there might be some value in incorporating footrails and kneerests into workstations, there is no guarantee that they would work effectively. Whether or not a standing aid might be effective might also depend on the user's level of knowledge on customary postural repertoire.

7.5 Conclusions

Within the scope of this study it can be concluded that:

- Discomfort during prolonged standing increases over time.
- Use of the footrail as a standing aid significantly reduced discomfort experienced in prolonged standing.
- Optimally, a footrail should have rails at 240mm and 360mm above the ground or one rail falling somewhere between these heights.
- The stick and kneerest either were not capable of significantly alleviating the discomfort experienced or they were not used optimally.
- Prolonged constrained standing causes discomfort predominantly in the lower back and legs.
- Prolonged constrained standing results in increased movement
- Subjects used the standing aids bilaterally.

7.6 References

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8 - SUMMARY OF RESULTS

In summary, the following findings arose from the preceding studies.

Survey of standing workers

The survey of standing workers showed that standing workers who had shorter working days had a lower mean discomfort rating than workers who had longer working days. In addition, the later they reported the onset of discomfort, the more severe it was. Severity of discomfort was affected by the presence of other workplace variables, e.g. performing lifting and carrying tasks.

The primary areas of discomfort or pain were the lower back and legs. Discomfort in the legs was detected earlier and rated as less severe than discomfort in the lower back which was detected later and reported as more severe. The results suggest that workers who were more mobile suffered less discomfort, particularly in the lower back.

Postural adaptations to workbench modifications

This study showed that there is no difference between male and female subjects in their postural adaptations to different workstations.

Task distance was found to influence posture significantly. When task distance increased, subjects adapted by flexing the lumbar spine and tilting the pelvis forward. The estimated compression and shear forces on the spine increased significantly for increased task distance. When the task was directly in front of the subjects, they flexed their necks more. This neck flexion was accompanied by an increase in thoracic kyphosis. This suggests that an optimal task distance is one that must trade neck flexion against forward bending of the trunk.

The most frequently reported area of discomfort was the legs, followed very closely by the neck.

Foot position was found to affect posture significantly. When there was no "toe space" under the workbench, subjects had to flex at the hips in order to focus on the task. Use of the footrail resulted in posterior pelvic tilt which decreases the depth of the lumbar curve. This is recommended as a means of removing stress from the intravertebral discs. However, subjects did not perceive this position as more comfortable than other positions even though it may have been more "beneficial". The success or otherwise of the implementation of footrests in industrial standing workstations will depend on task requirements and also the customary postural behaviour of workers.

Postural adaptations to standing VDT work

It was found that subjects working at the VDT tended to adopt an asymmetrical attitude with the left leg supporting, the right leg balancing. The balancing side was more flexed than the supporting side.

In addition, this study confirmed that when there is no "toe space" under the workbench, there is increased flexion at the hips with a corresponding increase of trunk flexion. Foot position was found to affect all the postural variables examined except neck flexion and plantar flexion. These variables were influenced by the height of the VDT screen.

The height of the VDT screen also influenced hip flexion and trunk inclination. As the screen moved higher, hip flexion tended to increase while neck flexion decreased. These findings suggest that increased hip flexion was used to get closer to the screen while flexion or extension of the neck was used to lose or gain eye height.

There was no significant relationship found between comfort rating and workspace constraints. However, within the relatively short period (60 minutes) of standing, discomfort increased steadily over time with a rapid increase in the last five minutes. The legs were reported as the area where discomfort was experienced most.

Screen height was found to influence accuracy in task performance. Performance was worst when the screen height was low and the subjects were looking down. Standing and working at the VDT resulted in significantly greater sway in the antero-posterior direction than standing still. Other than this, there was no difference between this work position and standing as still as possible.

Evaluation of standing aids for the workplace

Subjects experienced significantly less discomfort when they were using the footrail. They tended to keep their feet longer on the rung 360mm from the ground while they placed their feet more frequently on the run 240mm from the ground. Subjects who used the other two aids did not experience significantly less discomfort than the control group who had no aids.

It was also found that discomfort increased over time. Prolonged standing in one place resulted in increased movement or fidgeting. Discomfort was experienced predominantly in the legs. The lower back was the second most frequently reported area of discomfort.

Subjects interacted with the aids using the left and right sides of their bodies equally. It is possible that their mode of interaction was influenced by how well they had been instructed in the use of the aids, the presence of the other subjects, cultural differences and individual differences.

9 - CONCLUSIONS

Task Distance

Task distance dictates the positioning of the eyes and hands relative to the task and therefore plays a significant role in any postural adaptations to bring the eyes and hands into place. This work shows that these adaptations are made predominantly in the cervical spine, the lumbar spine and the pelvic region.

Foot Position

Foot position plays a large role in standing posture and where foot space is constrained, adaptations must be made in the trunk and legs. The absence of "toe space" under the workbench forces the feet further from the workbench. To compensate for the resulting increased distance between the worker and the task, the trunk has to be inclined further forward. This is achieved by increased hip flexion and trunk flexion.

The custom, highly prevalent in some industries, to use the floor space around workstations as temporary storage space is undesirable and can be seen as a risk factor for the development of low back or leg pain in standing workers.

Use of a footrest

The standing aids study **(section 7)** showed that people who were able to use a footrest experienced less discomfort than a control group. The study on postural adaptations to workbench modifications study **(section 4)**, however, showed no significant decrease in discomfort when the footrail was used. Subjects in the former study switched feet constantly whereas subjects in the latter study tended to keep one foot up on the rail for extended periods. The footrest may provide relief from discomfort during prolonged standing provided there is sufficient mobility. A static posture, even where lumbar lordosis is decreased and there is theoretically less intradiscal pressure, remains a static posture with all the attendant stresses caused by immobility. While discomfort in the lower back may be reduced, discomfort in the legs may increase as using the footrest may increase the load on the supporting leg so that it approaches that experienced when standing on one leg. As these studies only collected overall discomfort ratings and not ratings for individual body zones, it is not possible to confirm this.

VDT Screen Height

Hip flexion increased and neck flexion decreased as the VDT screen height was raised. It appears that subjects inclined forward as the screen height went up and then extended the cervical region in order to raise the eyes to obtain the visual angle necessary to focus on the screen. Task performance was worst when the screen height was low. The data suggests that an optimal VDT height for standing workers is one that places the centre of the screen level with the eyes and prevents excessive neck flexion or extension. For most subjects this optimal height fell between the middle and the high screen heights (485 - 700mm above the work surface).

Body areas affected

The primary areas of discomfort during standing were the legs, lower back and the neck. The results indicate that when people are standing for periods of, at least, between one and four hours, discomfort will be primarily felt in the legs. When they standing habitually for longer periods, this discomfort will tend to be felt in the lower back and then more severely. The discomfort in the neck region was encountered when the subjects were working on a visually demanding task (puzzle building).

Discomfort ratings

The detection and rating of discomfort and/or pain is highly subjective and it is possible that the ratings given by subjects in these studies were influenced by a variety of factors including cultural differences, individual physical differences and individual differences in perception. Nevertheless, these ratings can be compared across experimental conditions and it is also possible to highlight trends, e.g. that the later discomfort is perceived the more severe it is and that during prolonged standing discomfort increases over time.

Exposure

Even in a relatively short period of one hour, subjects reported increasing discomfort over time. This was also true over a period of four hours. When workers questioned in the survey were asked when they became aware of discomfort during the day, those who reported a later onset also tended to rate discomfort more severely. It is possible that, if monitored throughout the day, they would report discomfort earlier although it would be less severe.

Mobility

The data suggests that frequent movement (i.e. walking, lifting, carrying and stretching movements which predominantly involve the large pelvic and lower limb muscles) by the standing worker will result in less severe discomfort. In the survey of standing workers, those workers who walked around and were more active reported less discomfort. Subjects who used the standing aids moved more and more the longer they stood. It is possible that the main reason users of the footrest experienced less discomfort is that it gave them the opportunity for frequent, unstrained movement.

Methods

The use of stereophotogrammetry provided an accurate and efficient means of recording postural changes in standing workers. Body markers were improved for the study of VDT workers, making the use of the mirror to track obscured markers unnecessary. These improved body markers meant that postural changes on both sides of the body could be recorded at the same time.

The use of subjective comfort ratings has some weaknesses (see above) but it is possible that an EMG system, synchronised with the stereophotogrammetric system and monitoring the activity in key muscle groups, could be used to confirm these ratings and provide a useful measure of muscle strain and fatigue over time.

10 - RECOMMENDATIONS

Based on this work, the following recommendations for standing workers can be made :

- Workspace must provide adequate clearance under the bench so that foot position is not constrained, causing more forward bending.
- Workspace must not confine the feet to a small area that precludes adequate leg and foot movement.
- For every task, an optimal task distance must be found that minimises forward flexion while minimising neck flexion.
- An easily accessible footrest with at least one rung between 240mm and 360mm should be included in the standing workspace. It should be positioned so that the worker finds it easy to move both feet (alternately) on and off it so that movement of the legs is encouraged.
- Standing workers should be encouraged to move and walk about as much as they can.
- Where changes in work organisation can allow task rotation, this should be done to allow the worker to do tasks that involve standing, sitting and moving, especially walking.
- Rest breaks should be provided for standing workers as often as is practically possible. A five minute break every hour for exercising the legs would be optimal. Mobility during breaks should be encouraged over sitting.
- Since the standing aids were only moderately beneficial, the use of sit-stand workstations is supported.
- The top of the VDT screen for standing workers should be as close to eye level as possible.
- As asymmetry in postural adaptations appears to be influenced by whether the subject is left- or right-handed, standing workstations should cater for the handedness of the individual workers using them.

Further work :

The work presented in this thesis can be expanded both in the field and in the laboratory. Further studies of standing workers in the workplace should monitor workers throughout the working day, recording areas of discomfort and obtaining a discomfort rating for each body area. This would provide a clearer picture of the onset of discomfort during the working day and help to contribute to guidelines for rest periods. It would also provide a clearer idea of what areas of the body are affected over time.

In addition, other factors should be taken into account, e.g. length of time worked in that particular job or a similar one, current health status, visits to health practitioners about musculoskeletal problems. Job related variables should also be taken into account and quantified, e.g. how much lifting and carrying is done during the day, what shapes sizes and weights are lifted and carried, how much walking is there during the day? Analysis of this data will provide some indication of how problems in standing work are exacerbated by job related variables or vice versa.

Further laboratory studies should attempt to link EMG recordings of muscle activity in key postural muscle groups to three-dimensional postural data obtained via stereophotogrammetry in a real-time or near real-time environment. Periodic recording of areas of discomfort and discomfort ratings for each area, could be linked to the EMG and postural data, providing a clearer picture of the relationship between posture and the onset and experience of musculoskeletal stress.

Asymmetrical postural adaptations to workplace variables appear to be influenced by whether the subject is left- or right-handed. It would be useful to determine to what extent handedness influences working posture, particularly at the VDT. This data can then be used to design better workstations that take into account the handedness of individuals.

11 - EPILOGUE

Lo, this only have I found, that
God hath made man upright;
but they have sought out many inventions.
Ecclesiastes, 7 : 29

The overall conclusion to be drawn from this work is that prolonged standing is tiring, uncomfortable and sometimes painful. In other words, it begins to look very much that standing for long periods, with or without a standing aid, is generally not a good idea.

There is an often-quoted saying by Dr. Samuel Johnson, "Sir, a woman preaching is like a dog's walking on his hind legs. It is not done well; but you are surprised to find it done at all." (Concise Oxford Dictionary of Quotations, 1964) A long time has passed since he said this and women are standing up and preaching all over the place - and doing it well - but perhaps dogs have shown some good sense in remaining quadrupedal.

Man looks down on the quadrupeds and laughs indulgently when they parody him in circuses and side-shows. His upright stance has given him a colossal superiority complex. It has even been called "that majestic attitude which announces man's superiority over all the inhabitants of the globe". (in Barlow 1990, source not given)

Early 20th century anthropologists asked the question why evolutionary fate had treated man and the ape so differently. Sir Arthur Keith said at that time, "the one has been left in the obscurity of its native jungles, while the other has been given a glorious exodus leading to the domination of earth, sea and sky." (in Leakey and Lewin, 1992) The reason for this, anthropologists explained, was that while all apes had the same opportunity, only man had showed enough initiative.

This was based on the social ethic of the time (which is still pervasive) that success only comes through effort, the "no pain, no gain" philosophy. So there were no rewards for the indolent apes and they remained on all fours.

In 1928, the anthropologist Gregory said that "to suggest that man is an uptilted and still only partly refashioned four-footed animal, is to this day deemed impious and even blasphemous". (in Leakey and Lewin, 1992) This is considered true even today when molecular evidence shows that we are attached to the simian world through an unbroken chain of genetic inheritance. There is no doubt that we are apes of a kind - "rather odd, African apes". (Leakey and Lewin, 1992)

But is bipedalism really one of our great successes? Hellebrandt who did much work on standing in the 1930's and 40's, concluded that "the architectural design of the human is not conducive to stability. A segmented structure, its centre of gravity is placed high above a relatively small supporting base." (Hellebrandt and Franseen, 1943)

The musculoskeletal adaptations to bipedalism include the bending back of the sacrum so that it actually forms the roof of the pelvis. This is a mechanically risky set-up as the load carried by the lumbar vertebrae is transmitted to the sacrum which is nearly at right angles to the lumbar region. The last lumbar vertebra tends to slip ventrally leading to spondylolisthesis, a condition which is by no means rare. Spondylolisthesis is exacerbated by standing and lifting heavy and not so heavy objects, something human beings do all the time.

In 1993, 11% of the population of the United Kingdom reported that their activities had been restricted by back pain within the previous four weeks. (Jenner and Barry, 1995) If bipedalism and erect posture contribute directly to low back pain and to numerous other ills, the question is - why did it evolve at all? Hypotheses for bipedalism were put forward in the Review section of this thesis but essentially these hypotheses all say the same thing - that the adaptation to bipedalism was nothing more than an ape's way of living where an ape could not live.

Our spines are not perfectly adapted to the upright posture - more specifically, they have not evolved to withstand the monotonous and trying postures dictated by education, culture and industry. It seems rather that our spines are perfectly adapted for the odd bit of tree feeding and getting around from one clump of trees to another. Just because we can stand doesn't mean we have to.

As suggested by Barlow (1990), perhaps the role ergonomics must play is to help personal selection replace natural selection. In other words, we must learn to interact more intelligently with our environment. Instead of allowing our environment to emphasise our "design deficiencies" as upright animals, we should shape our environment to take these deficiencies into account. At the same time, we must consciously learn postural adaptations to our environment that take our weaknesses fully into account and can be maintained with ease and not discomfort. We have to learn the next step of our evolution ourselves.

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