THE EFFECT OF PERSONALISED ADJUSTMENTS TO COMPUTER WORKSTATIONS ON THE EFFICIENCY AND PHYSICAL COMFORT OF COMPUTER OPERATORS

BY

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THESIS

Submitted in fulfillment of the requirements for the degree Master of Science

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Rhodes University, 2004

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ABSTRACT

The present study sought to investigate the effects of a Standard workstation, designed for "average" users, on an anthropometrically diverse sample of computer operators, and to assess whether physical and perceptual responses, as well as performance efficiency were dependent on stature. Further investigation assessed the influence of personalised adjustments to the Standard workstation, based on the anthropometric characteristics of the subjects, as well as the introduction of a custom-designed 'floating' wrist support, on subject responses. All subjects (n=30) were tested in each of the three workstations: Standard, Personalised and Wrist Support. For analysis of responses in the Standard workstation, subjects were divided into three groups depending on their stature: Short (<1650mm), Medium (1650mm to 1800mm), Tall (>1800mm).

The musculoskeletal responses indicated that Tall subjects were forced to adopt the most awkward general body postures as a result of the low computer screen. However, the low screen allowed for the Short subjects to adopt the most natural general body postures, although levels of muscular activity in the upper trapezius suggest that the muscular load imposed on both Short and Tall subjects was significantly greater than that imposed on the Medium subjects. In addition, the Medium subjects' perceptions of the Standard workstation dimensions support the fact that this workstation was better suited to users with "average" morphologies.

The responses elicited in the Personalised and Wrist Support workstations were improved significantly when compared to the Standard workstation. Joint angles were more natural, upper trapezius EMG was reduced, standard of performance improved and perceptual responses indicated a diminished incidence of body and visual discomfort, as well as greater perceived satisfaction with these workstation dimensions. The improved physical responses suggest a decrease in the risk of developing cumulative trauma disorders. Although subjects were unaccustomed to the wrist support device, this workstation demonstrated a further reduction in the range of wrist angles, as well as a general positive attitude towards the concept.

ACKNOWLEDGEMENTS

I would like to acknowledge and thank the following people for their encouragement and support throughout the duration of this project:

Firstly, to my supervisor Professor Pat Scott for her intuitive guidance, support and encouragement, as well as her valuable time in the review of this thesis.

My sincere thanks to Francois Lamont, Candice Christie and Andrew Todd for their invaluable input, as well as to Crystal Steel, Jessica Hutchings, Sarah Skelton and Kelly Cowen for their assistance with the experimental phase of this project.

Finally, I would like to express my most sincere gratitude to my parents for their continual support in all that I do.

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CHAPTER I
INTRODUCTION

The literature is replete with the effect of the exponential change in technology on life in general and more specifically in the work setting. Moray (2000) stated that the dynamics of the world are such that there is a continuous evolution of society and with it there must be a corresponding evolution of ergonomics and human factors in order to deal with the new problems which continue to emerge between humans and their work environment. This is evident in the changes that have occurred from prehistoric times where men made weapons and tools for their basic survival. These were custom-made by the craftsmen for their own use, and a mismatch between the tool and the user therefore seldom occurred. A large portion of the population used to rely heavily on agriculture for personal food sources. In these cases the work performed was physically taxing and implements were therefore designed in order to ease the workload.

The industrial age, brought about by the invention of the steam engine, resulted in machinery replacing a great deal of the work previously performed by human physical capabilities. However, as Sugiyama (1991) noted, because this changed work tasks from being self-paced to being machine-paced, it in fact elevated the pace of work, which in turn increased the physical pressures placed on the human, and the predominant type of work in many work sites remained manual labour. This led to a growing number of work-related injuries as well as sub-optimal productivity, and so further mechanisation and automation was introduced. With the growing amount of automation as a result of sophisticated technology the industrial world is fast moving from a manufacturing society towards an information society, which has been accelerated by the rapid development of computer technology resulting in a growing number of office type jobs (Shackle, 1991). Despite a reduction in physically demanding jobs, with the increase in more sedentary type of work there has been an escalating number of chronic musculoskeletal disorders relating to prolonged static and awkward working postures. These global changes in the structure of the workforce are illustrated in Figure 1.
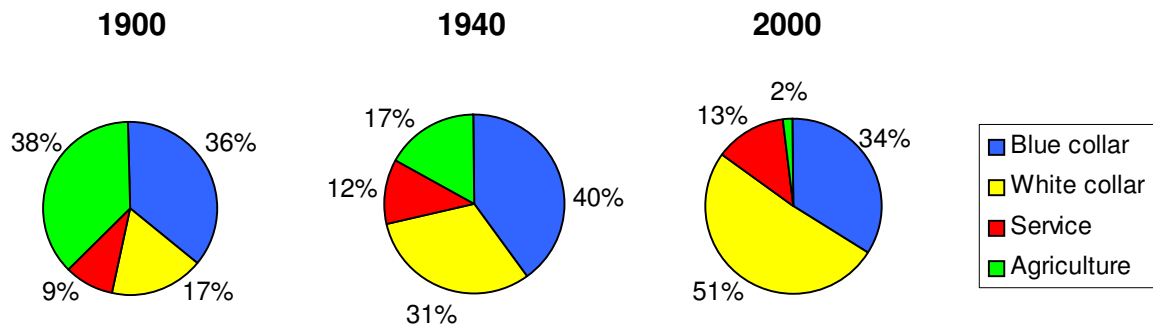
Figure 1: The structure of a developed country's workforce 1900 – 2000.
(Federal Civilian Workforce Statistics, 2000)

The exponential developments in computer technology have resulted in a growing dependence on computers in every day life in offices and homes, as well as in schools. These sophisticated advances in information and communication technology over the past few years have aimed to improve the accessibility of data, communication velocity and general office efficiency. Although technology has become highly sophisticated it cannot function without the human operator to input the necessary commands and data. Obtaining the best results from the technology therefore requires optimal efficiency of human operators, which is highly dependent on the implementation of sound ergonomic principles in the physical design of their workplace. Focusing on the human factor, Oborne (1995) suggested that the aim of ergonomics should be to maximise the operator's safety, comfort, efficiency and productivity.

Traditional office employees had multi-task jobs where the physical activities of workers varied substantially. With the move towards increased computer usage the tasks of office employees have become less diverse and most tasks are performed while sitting for long hours at a single computer workstation. Although this growing dependence on technology has resulted in a decrease in traditional forms of manual labour and the associated discomforts, Seghers *et al.* (2003) argue that new areas of discomfort have arisen and note that there has been a concomitant increase in the number of work-

related cumulative trauma disorders (CTDs) associated with sub-optimal working conditions. It is well known that static working postures, such as those maintained for eight hours or more per day by computer operators, lead to muscle fatigue, stiffness and pain (Grandjean *et al*., 1983; Amell and Kumar, 1999; Seth *et al.*, 1999). Furthermore, working postures often differ considerably from natural body positions, which according to Szeto and Ng (2000) increases the effort required to retain a predominantly static posture and results in a significant increase in discomfort, which in turn leads to a decrease in work efficiency.

Pheasant (1996) indicated that pain and discomfort associated with a badly designed computer workstation might interfere with the operator's concentration, which often results in errors and a reduction in performance efficiency. Furthermore, prolonged discomfort may negatively impact on operator health as it may lead to work-related musculoskeletal disorders, which will have repercussions in lost work time. The direct medical costs plus the indirect costs caused by absenteeism and the training and replacement of employees, will ultimately have a negative effect on productivity. In order to reduce the likelihood of such musculoskeletal problems, adjustments to these workstations and work tasks need to be implemented, and these interventions should be designed according to each individual operator's capabilities.

According to Oborne *et al.* (1993) people often ignore work-related discomfort as they grow accustomed to their work posture. They simply continue working and are unaware of the inappropriate postures causing the discomfort. In order to enhance efficiency the objective should be to sensitise the operators to any discomfort and to ensure that they are able to adopt working positions which are as close as possible to their natural postures. This would optimise the comfort and well-being of the operator, minimising the strain placed on them, and improving work efficiency.

In order to establish an ideal computer workstation ergonomic intervention is required. There are, however, several challenges which need to be overcome. The layout of computer workstations often have a limited means of modifying the arrangement to suit

personal needs. Although the chair is probably the easiest component to adjust, the position and dimensions of the desk, monitor, keyboard and mouse are important factors which need to be included in the assessment and design of computer workstations. Many studies have tended to include only one or two of these aspects and have then made general comments for the basis of changes. Mekhora *et al.* (2000) identified the need to include multiple aspects of the computer workstation before making recommendations. They argued that interactions of the various body segments with all aspects of the workstation should be considered by ergonomists before making adjustments to any workstation component.

It is necessary to take cognisance of the substantial variation of the anthropometric variables of computer operators. Botha and Bridger (1998) commented on the lack of anthropometric data in industrially developing countries (IDCs) such as South Africa, as well as a lack of awareness of the importance of ergonomic principles in the design of workstations. As a result there is often an incompatibility between the user and the work site in these areas. Computer workstations, for example, are often designed for the 50th percentile of the population using them. Consequently there are a vast number of users who are expected to simply adjust to, and use these computer workstations, regardless of their morphology. Kroemer and Grandjean (1997) strongly oppose this and suggested that although humans do have the ability to adjust to unnatural working postures, it is to their detriment and it is therefore recommended that for any workstation the design should be adjusted to suit the user, and not the other way round. This problem is exacerbated in countries such as South Africa where there is great ethnic diversity, because as Grandjean (1987) reported, there is great variation in the physical dimensions amongst individuals of different ethnic groups and populations. Therefore in order to achieve an optimum compromise between the diversity anthropometry of the operator population and the layout of the computer workstation components, the 5th to the 95th percentiles of the user population should be considered.

Recognising this "human variability", several authors have suggested that the only feasible way to accommodate the anthropometrical diversity is to build adjustability into

the workstation so that each individual is able to adjust the various components to correspond with their specific morphology (Grandjean *et al.*, 1983; Miller and Suther, 1983; Pheasant, 1996). Unfortunately many computer workstations are set, with no means of adjustments, and as a result are unsuited to a large portion of the working population. There is substantial controversy in the area of computer workstation design in terms of what heights and/or angles the various components should be positioned in order to ensure that working postures are as close to neutral as possible.

Working postures that differ considerably from neutral body positions exacerbate the load placed on the musculoskeletal system. Computer workstations are often designed in such a way that the position of the monitor forces flexion of the cervical spine thereby increasing the neck extensor muscle load. Furthermore, the positioning of the keyboard and mouse are responsible for excessive wrist extension and ulnar deviation. Computer operators of extreme anthropometric characteristics, who are expected to adapt to workstations designed for operators of average morphology, are forced to adopt more awkward and unnatural working postures. The musculoskeletal load imposed by these awkward work postures is intensified by the static nature of computer work. Recent studies have demonstrated a significant reduction in the static load imposed upon the neck and shoulder musculature with the introduction of an upper extremity support (Aarås *et al.*, 1998; Cook and Burgess-Limerick, 2004).

Unfortunately in industrially developing countries, such as South Africa, total replacement of existing, non-adjustable workstations with ergonomically designed workstations is not feasible due to the tremendous costs involved. Mekhora *et al.* (2000) therefore suggested that inexpensive ergonomics principles need to be implemented. These "low-cost" interventions can be applied simply by, for example, using books, bricks or wooden platforms to raise a surface, or making small alterations to the existing workstation. Even a moderate decrease in the awkwardness of a working posture will reduce symptoms of discomfort and in effect increase profitability through improved operator efficiency and reduced absenteeism brought about by CTDs. Aarås *et al.* (2002) suggested that ergonomic interventions should take place in the planning stages

of any workstation design. They argued that this will not only reduce the costs involved in making adjustments to an already existing workstation, but will also prevent the development of chronic work-related injuries, which once developed reduce profitability through an increase in both direct and indirect costs. They are also extremely difficult to cure even with the removal of the worst risk factor within the workstation design.

In order to address the effect of poorly designed computer workstations on human operators their responses need to be taken into consideration. Being such a complex species it is necessary to address any problems associated with human beings with a holistic approach (Charteris *et al.*, 1976). When assessing an area of concern the biophysical responses address the awkward working postures adopted by the user. These unnatural joint angles often lead to elevated levels of muscular activity because of the demand required to maintain the posture, and this can be assessed with the use of electromyography. It is also important to take cognisance of the user's perceptual responses towards the workstation and the discomfort associated with awkward postures and elevated muscle activity. These factors aid in identifying the risk of CTD development.

STATEMENT OF THE PROBLEM

Computer operators of a wide range of statures are often required to carry out tasks for prolonged periods of time at similar workstations that have a limited means of adjustment. These work areas are generally designed for users of "average" morphology, and as a result short and tall operators are required to adjust their working postures to the detriment of their personal comfort, well-being and efficiency in work output.

In order to assess the benefits of a personalised computer workstation designed specifically to suit each individual's morphology, the objective of this research was to investigate and compare anatomical, physiological and perceptual responses of Short (S), Medium (M) and Tall (T) subjects working at an Average Standard (A) workstation,

and then to compare the responses of the group as a whole in the Average Standard workstation with those obtained in a Personalised (P) and a Personalised with Wrist Support (WS) computer workstation, and to assess the effect on performance efficiency.

RESEARCH HYPOTHESIS

It was expected that the Average Standard workstation, which was designed for users with "average" anthropometric characteristics, would have a negative impact specifically on the responses of Short and Tall subjects. The workstations designed according to each individual's anthropometric characteristics (Personalised and Wrist Support) took stature into account and would therefore eradicate stature-related differences by reducing awkward working postures of all subjects thereby enabling joint angles to be closer to neutral positions. This was expected to reduce the load placed on the associated musculature thus resulting in lower muscle activity, less discomfort and therefore a greater preference for these workstations. It was proposed that the improved working posture would augment work efficiency.

STATISTICAL HYPOTHESES

In order to address the above general hypothesis of expectation two discrete hypotheses were proposed to address, firstly the effect of stature on subject responses in a 'Standard' workstation; and secondly to investigate the effect of workstation modifications on computer operator responses.

Hypothesis 1: SUBJECTS

It was hypothesised that there would be no difference between the responses attained for Short, Medium and Tall subjects within the Standard workstation. This hypothesis was addressed within the four areas of biophysical, physiological, perceptual and performance responses.

a   Ho: $\mu JA_S = \mu JA_M = \mu JA_T$ (Biophysical – JA)

        Ha: $\mu JA_S \neq \mu JA_M \neq \mu JA_T$

b   Ho: $\mu EMG_S = \mu EMG_M = \mu EMG_T$ (Physiological – EMG)

        Ha: $\mu EMG_S \neq \mu EMG_M \neq \mu EMG_T$

c   Ho: $\mu D_S = \mu D_M = \mu D_T$ (Perceptual – D)

        Ha: $\mu D_S \neq \mu D_M \neq \mu D_T$

d   Ho: $\mu PERF_S = \mu PERF_M = \mu PERF_T$ (Performance efficiency – PERF)

        Ha: $\mu PERF_S \neq \mu PERF_M \neq \mu PERF_T$

Where:
S	=	Short subject group
M	=	Medium subject group
T	=	Tall subject group
JA	=	Joint angle
EMG	=	Electromyography
D	=	Body and visual discomfort, workstation perceptions
PERF	=	Performance efficiency

Hypothesis 2: WORKSTATIONS

It was hypothesised that there would be no difference in the responses obtained for the entire group (n=30) at the Average Standard, Personalised and Wrist Support workstations. This hypothesis was addressed within the four areas of biophysical, physiological, perceptual and performance responses.

a   Ho: $\mu JA_A = \mu JA_P = \mu JA_{WS}$ (Biophysical – JA)

          Ha: $\mu JA_A \neq \mu JA_P \neq \mu JA_{WS}$

b   Ho: $\mu EMG_A = \mu EMG_P = \mu EMG_{WS}$ (Physiological – EMG)

          Ha: $\mu EMG_A \neq \mu EMG_P \neq \mu EMG_{WS}$

c   Ho: $\mu D_A = \mu D_P = \mu D_{WS}$ (Perceptual – D)

          Ha: $\mu D_A \neq \mu D_P \neq \mu D_{WS}$

d   Ho: $\mu PERF_A = \mu PERF_P = \mu PERF_{WS}$ (Performance efficiency – PERF)

          Ha: $\mu PERF_A \neq \mu PERF_P \neq \mu PERF_{WS}$

Where: A   =   Average Standard workstation

            P   =   Personalised workstation

            WS   =   Wrist Support workstation

            JA   =   Joint angle

            EMG   =   Electromyography

            D   =   Body and visual discomfort, workstation perceptions, preference

            PERF   =   Performance efficiency

DELIMITATIONS

The subject pool was limited to Rhodes University students who had sufficient computer experience and who spent a substantial amount of time operating a computer. Reasonably good typing skills was another prerequisite for subjects. All of those tested were either specialising in Computer Science or Information Systems, or they were post-graduate students who were highly dependent on computers for every day use.

The 30 subjects were assigned into one of three experimental groups based on their stature (Short, Medium and Tall). The aim of the study was to determine how different workstations influenced various responses of these individuals. Each of the subjects was therefore tested in the Standard, Personalised and Wrist Support workstations and skeletal, electromyographic and perceptual responses were monitored during and after completion of a computer-based task which was used to assess their performance efficiency at the three computer workstations.

LIMITATIONS

When investigating physical and perceptual responses of humans it is impossible to control all factors impinging on the results. However, every effort was made to ensure rigorous control of as many influencing factors as possible. The following limitations remained and should be considered when examining the results.

The subjects' personalities, as well as mood and level of arousal on the day of testing may have varied substantially when comparing the three testing days. This may have affected their performances as well as their perceptions of the workstations.

Although subjects were familiarised for 30 minutes prior to testing in each of the three workstations, the environment in which they were tested was not familiar to them, and the Personalised and Wrist Support workstations were very different to what they were accustomed to. Furthermore, the equipment used required markers and electrodes to be

placed on the skin throughout testing. These factors augmented the lack of familiarity and may have influenced the subjects' responses.

The wrist support introduced in Condition 3 was not as free flowing as intended due to a manufacturing limit, thus making the device slightly restrictive and not as easy to operate as should have been the case.

The placement of the surface markers to measure the skeletal positioning, and the actual measuring of the small ranges of movement of the wrist on the video made absolute accuracy of the measurements difficult, although every effort was made to standardise the positioning of the markers and the assessment of the joint angles.

Electromyography electrodes are subject to crosstalk from nearby muscle activity. Electrode placement on forearm muscles can be difficult because the size of the muscle is small relative to the size of the electrode. Great care was taken to accurately place the electrodes on the correct muscle while minimising crosstalk.

CHAPTER II
REVIEW OF RELATED LITERATURE

INTRODUCTION

Although there has been a general increase in mechanisation and automation in most industries, the human operator is still required to programme and control operations with the use of advanced computer technology. Appropriate designing of computer workstations for the human operator is therefore essential to ensure that procedures are executed successfully.

The sophistication of technology has resulted in computer operators being required to do very limited physical activity when at the workstation. Whereas in the past people were required to walk around the workplace to complete various tasks, as each was carried out in a different area within the office, in contrast computer operators simply enter data and commands while remaining in a fairly static seated position (Grandjean, 1987). Furthermore, computer workstations are often designed for users of "average" anthropometric characteristics regardless of whether they are to be used by children or adults of extreme stature. This often results in the operator having to adopt an awkward working posture, and this, together with the static nature of the work, can lead to considerable discomfort and work-related cumulative trauma disorders.

However, although the amount of physical activity is limited, Smith (1997) pointed out that there is substantial mental effort required when operating computers, and according to Wærsted *et al.* (1991) complex tasks requiring a great deal of concentration lead to an increase in muscle tension. The static load induced by these mental demands and associated psychological stresses lead to localised muscle fatigue, specifically in the neck and shoulder region, which will result in pain and impaired function (Ekberg *et al.*, 1995).

GENERAL LAYOUT AND OFFICE SETTINGS

Wang and Chen (2000) proposed that as the workforce becomes more dependent on computers, the need for correct and efficient physical and environmental design of offices becomes increasingly critical. While the focus of this project was specifically on the design of the PC set-up, when trying to optimise a computer workstation it is essential to take cognisance of the entire working ambience. Two 'traditional' problems are lighting and noise. According to Shahnavaz (1982) the visual performance and comfort of computer operators is dependent on ambient workroom illumination, contrasts, screen characteristics and workplace dimensions. He does, however, indicate that these factors are influenced by personal preferences as well as the task itself. More recently Takahashi *et al.* (2001) identified luminance of the computer and general noise as two of the crucial factors that affect computer operator performance. They found that subjective symptoms of fatigue and discomfort were higher with a high luminance of the computer display (above 90 $sd.m^{-2}$) and under noisy conditions where the level of distraction was great.

Bridger (1995) identified glare and reflection as significant factors which should be avoided when designing a computer workstation in order to prevent viewing difficulty, discomfort and distraction. He defined glare as a gross overloading of the adaptation process of the eye, brought about by over exposure of the retina to light. He also observed that as the light source was positioned closer to the optical axis the amount of glare increased and visual performance became impaired, and as Bergqvist *et al.* (1995) found, glare is associated with a high incidence of cervical diagnoses. Similarly, Jensen *et al.* (2002a) reported that glare elevates the visual effort required to look at the screen thereby inducing more static postures and increasing musculoskeletal discomfort. It is therefore recommended that the light sources be carefully positioned since they do not only produce glare, but also often generate reflections on the glass surface of the screen. Lighting should be considered in the initial design of computer laboratories or offices in order to avoid the costs associated with lighting alterations required as a result of unnecessary glare and reflections.

Wang and Chen (2000) suggested that the optimal illumination is somewhere in the range of 400 – 850 lux depending on personal preferences. Illumination exceeding these values increases the risk of troublesome reflections and deep shadows. The position of the light source is also important. A light source located behind the operator may cause a reflective glare on the computer screen, and if placed in front of the operator may result in direct glare. The light should also not be positioned directly above the operator as this will dim the characters on the screen and result in blurred reflections (Bridger, 1995). In order to overcome these lighting constraints, Pheasant (1996) suggested that it is preferable to have fluorescent light fixtures positioned parallel to and on either side of the operator as a means of indirect lighting. He defined indirect lighting as that which reflects 90% of its light off the ceiling and walls. In the same way, Aarås *et al.* (1998) found that indirect lighting reduced the incidence of complaints concerning visual discomfort and fatigue.

In terms of noise, Parsons (2000) noted that although a certain amount of noise can enhance performance by increasing levels of arousal, noise can also be a distraction which adds to the "overall workload" and therefore hinders performance. For a daily eight-hour exposure to noise Parsons (2000) recommended that it should not exceed 85 – 90 dB in order to prevent long-term noise induced hearing loss. However, noise at this level would be counterproductive in any workplace where mental demands are high. According to an individual's perception of noise a continuous but low noise may be annoying and lead to short-term changes in heart rate, blood pressure and adrenalin production (Parsons, 2000). More recent studies reveal that office noise levels should not exceed 50 – 55dB (Kim *et al.*, 2003a). This will mask surrounding conversations and telephone calls, while allowing undisturbed speech communication between other employees.

There is a general consensus that optimal lighting and minimal noise at computer workstations will assist in decreasing levels of nervous muscle tension, which in turn results in a reduced level of mental effort and physical discomfort, thus enhancing performance efficiency.

WORKSTATION DESIGN

Seated work

Humans have adapted to a bipedal and physically active lifestyle, and yet the number of seated jobs which require energy consumption close to resting levels have increased substantially (Winkel and Jørgensen, 1986). Most computer operators maintain a seated posture for a large part of their working day. Carter and Banister (1994) pointed out that there are several advantages and disadvantages associated with a seated posture. Sitting takes the weight off the legs, increases stability and reduces energy expenditure thereby alleviating fatigue and lowering the demand on circulation, but it also leads to slackening of the abdominal muscles and an unnatural kyphosis of the spine, which increases the pressure within the intervertebral discs (Figure 2). They argued that sitting stresses the spine and the slackened muscles of the back.
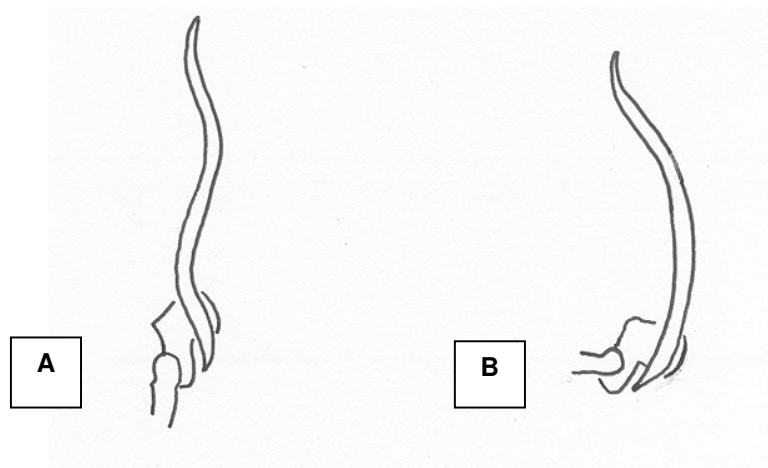
Figure 2: The natural curvature of the spine (A) while standing compared to (B) while seated.
(Adapted from Grandjean, 1987)

Prolonged seated postures lead to discomfort due to the static load placed on the neck and back (Turville *et al.*, 1998). Fenety *et al.* (2000) observed that when people first sit there is little seated movement, but as time progresses there tends to be an increase in "in-chair postural adjustments". Helander and Zhang (1997) considered the rise in both discomfort and seated movements with progressive time spent in a seated position, and

suggested that people are inclined to continuously alter their posture in order to relieve the build up of pressure and discomfort associated with prolonged sitting.

There appears to be a lack of consensus concerning the "ideal" seated work posture for computer operators. Hochanadel (1995) recommended that the knees be at a slightly higher level than the hips in order to ensure that the popliteal fossa clears the front edge of the chair thus minimising the pressure on the posterior surface of the knee and thigh. On the other hand, Pheasant (1996) suggested that when seated there should be a 90° angle at the knee, but he does agree that if the seat height is too high the pressure on the posterior thigh may lead to a reduction in the circulation to the lower extremities, consequent swollen feet and a considerable amount of discomfort. Harvey and Peper (1997) therefore recommended that the optimal chair height be determined by leg length and according to Carter and Banister (1994) it should range between 380 – 570mm above the ground.

Coleman *et al.* (1998) reported that low cost interventions can be implemented in order to overcome these height related problems, and suggested that in the case of a chair that is too high a footrest could be used so that feet are firmly supported and pressure on the legs reduced. A chair that is too low can simply be raised using a platform in order to retain the optimal seated working posture.

Sauter *et al.* (1991) suggested that an erect sitting posture with an elevated backrest was important for reducing the static loads imposed on the trunk. They did, however, point out that subjects adopted a stooped posture in order to relieve the static demands and associated discomfort of prolonged erect sitting. According to Straker and Mekhora (2000) a similar forward stooping posture is associated with a low computer screen when compared to a high screen and it results in elevated thoracic erector spinae muscle activity levels. Furthermore Carter and Banister (1994) stated that slumping forward places the ligaments and muscles in the lumbar region under a great deal of tension. Hochanadel (1995) found that a slightly reclined trunk posture of 100° – 110° reduces the intradiscal pressure of the spine as well as the electromyographic activity in

the back muscles, but as Burgess-Limerick *et al.* (2000) pointed out, if the trunk is reclined further than 110° there is an increase in tension of the anterior neck musculature due to the neck flexion required to maintain the same visual focal point. Fujimaki and Mitsuya (2002) also recommended a reclining posture, but they did caution that this may affect the users' ability to place their feet flat on the ground and thus suggested a footrest in order to prevent lower limb discomfort.

Several authors have stressed the importance of the use of a backrest (Aarås *et al.,* 1997; Vergara and Page, 2000). It has been found that limited use of a backrest is associated with a high level of kyphosis in the lumbar spine with a large amount of in-chair movement indicating discomfort. It has also been noted that only backrests with a substantial amount of lumbar support bring about a reduction in discomfort in the lumbar region of the spine. The optimal height of the lumbar support has received considerable attention. In a study done by Coleman *et al.* (1998) they discovered that body mass index (BMI) was more closely associated with the height of the support than was stature. They found that obese people (high BMI) tended to prefer a higher lumbar support compared to those with a lower BMI, and they therefore suggested that the height of the lumbar support should be adjustable from 150 – 250mm above the seat in order to suit each individual's needs and preferences.

In terms of the backrest dimensions Grandjean (1987) recommended that only longer backrests (between 480 – 500mm) be used in the design of office chairs, as these are more effective in supporting the weight of the trunk and result in enhanced sitting comfort. Coleman *et al.* (1998) found that the depth of the backrest is seldom adjusted since the seat pan often provides a definite location for the buttocks and any deviation will increase the pressure on the ischial tuberostities. According to Pheasant (1996) this chair dimension should however be adjusted according to the length of the upper leg of the user as this will allow all users to make full use of the backrest without placing pressure on the posterior surface of the knee. Helander *et al.* (1995) emphasised the need for adjustability so that the anthropometric differences among users, what they are used to, and their personal preferences can be accommodated so that users can alter

their postures when sitting for prolonged periods of time in order to reduce the strain and build up of discomfort experienced by them.

Working surface

Karlqvist (1998) identified the need for desks of varying heights for people of diverse anthropometric characteristics. When the working surface is too high, short people cannot reach the floor for foot support thus causing them to sit on the edge of the chair and making it impossible for them to make use of the backrest. If the chair is lowered in order to obtain foot support the short person has to lift their shoulders and adjust their wrist postures to reach and use the keyboard and mouse thus placing the upper extremity in a sub-optimal and unnatural posture. If, on the other hand, the desk is too low, tall people are required to flex the trunk which results in fatigue and discomfort over prolonged working hours.

Coleman *et al.* (1998) recognised the tendency of desks to be of a fixed height, but according to Hochanadel (1995), the height of the desk is not a key issue in computer workstation design. As recognised earlier, when the chair has to be raised for a short person to place their upper extremity in the optimal position, a footrest can be used to ensure that their feet are fully supported, and if a table is too low for a tall computer operator, the keyboard and monitor can be raised using low cost blocks in order to position the head, neck and upper extremity in a neutral working posture. However, in the case of a low table Cook and Burgess-Limerick (2003) pointed out that leg clearance might become an issue in which case the desk would have to be raised.

The working surface must be large enough for all computer accessories to be positioned at ergonomically acceptable horizontal distances from the operator, and as pointed out by Carter and Banister (1994) individual preferences also need to be taken into consideration. Bergqvist *et al.* (1995) noted that insufficient table space could cause higher levels of back, neck and shoulder discomfort and a greater risk of developing a cumulative trauma injury known as tension neck syndrome.

Monitor placement

Individuals working at visual display terminals are often required to sit in relatively static postures in front of computer monitors for prolonged periods of time. The correct placement of the screen – height, angle and distance – is therefore essential in the prevention of discomfort and the consequent health complaints of the musculoskeletal system, particularly the neck and shoulder region, and the visual system (Bauer and Wittig, 1998). Burgess-Limerick *et al.* (2000) pointed out that for a seated operator to focus on a visual target placed at horizontal eye level they must either compromise their preferred gaze angles or place their cervical regions and atlanto-occipital joint in flexion. This trade-off is illustrated in Figure 3. Hence Kim *et al.* (2003b) argued that when determining the 'correct' placement of the computer monitor the musculoskeletal system should therefore be considered together with the visual system.
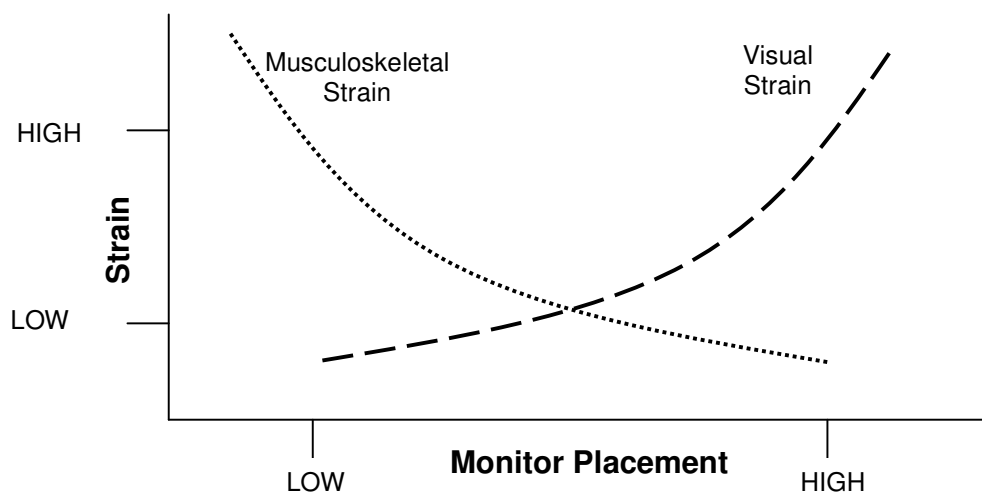
Figure 3: Monitor placement strain model.
(Adapted from Sommerich *et al.,* 2001)

Visual system

The visual system is one of the most important ways in which humans can obtain information from their environment. Convergence of the optical axes of the two eyes at the object being looked at, so that the image falls onto the corresponding part of the

retina in each eye, allows for binocular vision (Grandjean, 1987). It is well known that the ability of the eye to bring into focus objects at varying distances is referred to as "accommodation". An object is only seen clearly when refraction through the cornea and lens produces a sharp image on the retina, and without accommodation the image of a close object would fall behind the retina thus giving a blurred impression. When focusing on near objects the circular ciliary muscles contract thus increasing the curvature of the lens and when viewing distant objects these muscles relax (Figure 4). It therefore follows that in order to maintain focus on a near object, the ciliary muscles must be continuously contracted; a position which if prolonged is likely to lead to fatigue.
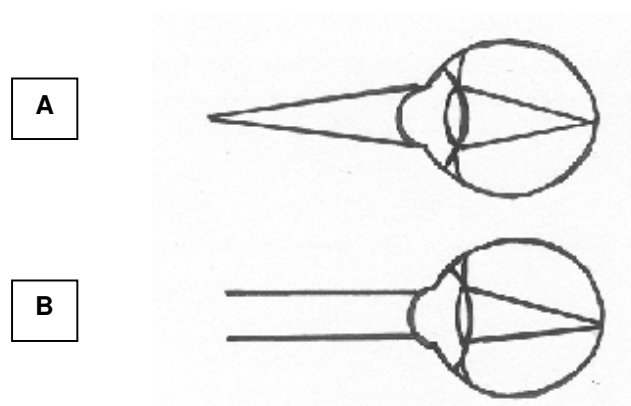
Figure 4: **Changes within the lens when focusing on (A) close objects, and (B) distant objects.**
(Adapted from Tortora and Grabowski, 1996).

Jung *et al.* (2000) emphasised the importance of vision for computer related work where information must continuously be assessed on the screen, source documents must be read, and often the keyboard must be visually scanned to find the appropriate function keys. The visual capacity and limitations of the human operator must therefore be considered together with the task requirements when setting up a computer workstation. Improper workstation design can place excessive visual demands on the operator, which increases the likelihood of visual fatigue, which in turn will result in a break down in efficiency and the production of erroneous work.

An important issue concerning the visual system in conjunction with computer use is visual strain and fatigue. Tyrrell and Leibowitz (1990) defined visual strain as a vague discomfort that may be localised in the head or eyes, and visual fatigue as any subjective visual symptom or distress resulting from the use of one's eyes. Evidence suggests that visual aids, in the form of glasses, exacerbate visual computer-related problems, and according to Aarås *et al.* (1998) this is irrespective of the type of glasses. Lie and Watten (1994) proposed that the symptoms indicative of a generalised ocular strain response include recession of the near point of accommodation and convergence, delayed rates of accommodation, shifts of accommodation towards the resting point of vergence (RPV) (which is the point at which the eyes converge when there is no object upon which to focus), changes in muscle balance and induced myopia. However, this oculomotor strain can be reduced by intermittent scanning of remote parts of the visual field, closing the eyes for short periods, frequent blinking, postural changes and rest breaks. Lie and Watten (1994) found that computer operators tend to be too focused on the screen, thus indicating that computer work offers less opportunity to develop proper strategies for coping with oculomotor strain.

Research by Jaschinski-Kruza (1991) indicated that prolonged 'near work' forces the ocular muscles to maintain contraction for the eyes to converge and the lens to accommodate in order to focus. He found that a monitor placed at 0.5 metres from the operator increased visual strain as opposed to a monitor placed at one metre. However, at a distance as great as one metre the screen would have to be considerably larger for the text to be of a readable size. Turville *et al.* (1998) argued that the basis of visual fatigue is prolonged visual activity performed during work done in close proximity.

A link between the preferred viewing distance and the viewing angle was identified by Ankrum (1997). When looking directly ahead the RPV was found to be 1.12 metres yet when the gaze angle was lowered 30° the RPV was found to be 0.87 metres. Ankrum (1997) argued that objects viewed at a distance closer than the RPV would result in eyestrain, but in order to view closer objects strain could be prevented simply by lowering the angle at which they are to be viewed. In addition Tyrrell and Leibowitz

(1990) pointed out that prior to the mass move towards computerised jobs, traditional desk jobs permitted a downward gaze of at least 25° below the horizontal. The reason being that a downward gaze for near visual work requires less visual effort in the vergence system since the resting level tends to shift closer with the downward gaze.

A further advantage of a lower monitor angle was identified by Tsubota and Nakamori (1993); they indicated that at a lower gaze angle tear evaporation is decreased, as less of the eyeball is exposed to the atmosphere and as a result the risk of dry eye syndrome is reduced. However, Cook and Burgess-Limerick (2003) identified that with a lower monitor there is increased likelihood of glare, which would have a deleterious effect on the visual system.

Musculoskeletal system

The working posture in terms of head and neck positions has long been an important area of interest and yet according to Turville *et al.* (1998) there is continuous debate and controversy regarding the optimal posture. Yoganandan *et al.* (2001) point out that the cervical spine is a delicate set of structures and is prone to degenerative processes and arthrosis especially when its natural lordotic curvature is disrupted.

Based on the belief that the resting point of the eye is 15° below the horizontal when the head is in an upright position, computer monitors have been recommended to be positioned slightly below eye-level (Ankrum, 1997; Burgess-Limerick *et al.*, 2000). The ear-eye line is, however, about 15° above the horizontal in erect posture due to the natural anterior curvature of the cervical spine. A computer screen placed below the ear-eye line therefore forces the cervical spine into flexion. This increased flexion increases the horizontal distance of the centre of mass of the head from its axis of rotation. Due to this shift in the centre of mass, a greater torque is required in the extensor muscles in order to maintain static equilibrium (Burgess-Limerick *et al.*, 2000). De Wall *et al.* (1992) identified the musculoskeletal benefit of the lower flexor moment and thus recommended increasing the height of the visual target in order to decrease the muscular effort. They suggest that a neck extension of 30° places the centre of mass approximately above the

axis of rotation. In a study comparing a monitor positioned so that the direction of sight towards the middle of the screen was 15° below and 15° above the horizontal, De Wall *et al.* (1992) found that the higher monitor was preferred as it placed the cervical spine in a more natural posture thus reducing muscular tension. Contrary to this Ankrum and Nemeth (1995) suggested that a lower monitor allows a greater range of neck postures, so when the operator starts to experience discomfort, they have greater freedom of movement in order to reduce the discomfort in the neck and shoulder region.

It is evident that in general a lower monitor is recommended for viewing comfort, while a higher monitor decreases the load placed on musculoskeletal system. According to Straker and Mekhora (2000) these conflicting views may reflect differences in individual capacities and task demands. Furthermore, they argued that computer operators may develop physically to suit the monitor height they are exposed to by changes in muscle length and strength, ligament length and even bone structure.

Interestingly Aarås *et al.* (1998) found a correlation between visual discomfort and pain in the neck and shoulder region. Similarly, in a study by Lie and Watten (1994) it was reported that induced oculomotor stress resulted in greater EMG activity in the head, neck, shoulder and upper back muscles, indicating that accommodation and vergence performance requires synergetic assistance from other muscles in managing visual stress associated with work performed in close proximity.

Keyboard placement

The computer keyboard is the most frequently used data input device. Although the keyboard has only marginal adjustability, Fagarasanu and Kumar (2003) point out that it is used by all computer operators regardless of age, morphology, gender and performance. Recent research has shown that because of the high level of task repetition, high forces and awkward postures associated with typing, the computer keyboard is often identified as the main cause of the frequent cumulative trauma disorders suffered by computer operators (Smutz *et al.*, 1994; Amell and Kumar, 1999; Gilad and Harrel, 2000).

Chan *et al.* (2003) stated that a computer operator working an eight-hour day can make up to 173 000 keystrokes per day, which is clear evidence of task repetition and occupational overuse of the fingers. However, not all computer operators use all 10 fingers to type, and Amell and Kumar (1999) suggest that the excessive use of certain fingers when typing leads to a high level of task repetition especially in those fingers. At the same time Seth *et al.* (1999) argue that the other fingers remain in fairly static postures and may thus fatigue comparatively faster.

In addition to the frequency of striking the keys, computer operators often hit the keys with excessive force, which in itself is a risk factor and which will in turn exacerbate the likelihood of CTDs. Fernström *et al.* (1994) reported that more recently designed keyboards have attempted to alleviate this problem by requiring a considerably lower key-press force. In modern keyboards the key-press force ranges from 0.2N – 0.9N as opposed to earlier keyboards, which varied between 0.57N – 2.27N (Rose, 1991). Radwin and Jeng (1997) established this to be effective in reducing the strain experienced by computer operators as the force exerted when pressing keys was decreased by 15% when the key-press force was reduced from 0.71N – 0.31N. They also observed that keyboards with a higher key-press force were associated with a higher level of fatigue in the operator. While this may be the case, Rose (1991) cautioned that although a lighter key-press force may allow faster keying, the forearms and in particular the wrist and finger extensors, are more likely to fatigue at a faster rate as their muscular activity is increased. Fernström *et al*. (1994) supported this argument and stated that in order to decrease the muscular strain in the shoulder muscles, the wrist extensors and finger extensor musculature, the keystrike force should not be minimised. They indicated that the fingers should be able to rest on the keyboard without characters being typed. Keys are therefore generally balanced with springs so that the weight of the fingers is not sufficient to push down a key and an active finger flexion is required to type, while finger extension is needed to reposition the finger. However, according to Forsman *et al.* (2002) operators tend not to rely on the spring effect and as a result they work with their fingers in an extended position above the keyboard. If the fingers cannot be rested, then neither can the muscles of the arm, and consequently the

sustained static load placed on the forearm and shoulder is increased, resulting in an elevated probability of the onset of CTDs.

Wrist posture

Operating a computer keyboard forces the wrists into awkward working postures. Gilad and Harrel (2000) point out that the wrist's natural operating zone ranges from 15° of extension to 20° of flexion with less than 20° of either ulnar or radial deviation. For keyboard operators this neutral posture is however seldom evident. A study by Cail and Aptel (2003) demonstrated a strong relationship between wrist complaints and wrist articular angles exceeding those necessary for a neutral posture. The shoulder span of most computer operators exceeds the width of the keyboard thus forcing a substantial amount of ulnar deviation. Serina *et al.* (1999) found that 20% of subjects had left wrist ulnar deviation of greater than 20°, and 41% had right wrist ulnar deviation greater than 20°. The wrists tend also to be extended when using a keyboard depending on the angle and height of the keyboard above the ground, as well as the various anthropometric characteristics of the operator (Nakaseko *et al.*, 1985; Hedge *et al.*, 1999). In a study by Serina *et al.* (1999) most of the subjects typed with wrist extension exceeding 15°, with some wrist extension of up to 30°. Furthermore, Serina *et al.* (1999) state that although the wrists and forearms appear to be almost stationary during typing, peak wrist angular velocities and accelerations were similar to wrist motions of industrial workers performing other tasks associated with high CTD risk.

Workstation interventions

Several interventions have been suggested as a means of modifying the assumed typing posture of the forearms and wrists, as well as decreasing the pressure within the carpal tunnel. These include the height of the keyboard above the ground, the slope of the keyboard, wrist rests and alternative keyboards.

In terms of keyboard height above the ground there appear to be conflicting views. With the use of a keyboard positioned on a lower working surface, a neutral wrist posture with minimal wrist extension results in fingernail contact with the keyboard rather than finger

pad contact. Rose (1991) argued that a lower keyboard therefore requires further extension of the wrists and fingers for keying without fingernail contact. Nakaseko *et al.* (1985) suggested that the lower keyboard would initially encourage flexion, but as the associated musculature tires so the wrists will be rested on the desk or wrist supports, which will then exacerbate wrist extension. However, a short operator using a high keyboard is required to elevate the shoulders thus increasing their static load (Rose, 1991). Sauter *et al.* (1991) also found that a keyboard positioned higher than elbow level increased arm discomfort.

Tepper *et al.* (2003) reported that an inclined working area with the keyboard located close to the screen enables total forearm support and neutral wrist postures. However, this workstation forces the elbow joints into undesirable angles of less than 90°. Earlier Kumar (1994) found that individuals tended to prefer a keyboard that was positioned closer to the monitor. He did however identify that a lower keyboard reduced the static postural and muscular load. Another consideration is the typing ability of the operator because with a lowered keyboard, computer operators with poor typing skills are required to adjust their gaze between the keyboard and the screen which, Aarås *et al.* (1998) identified as a source of repetitive movement of the head, which may lead to discomfort and musculoskeletal problems in the neck and shoulders. Considering these rather conflicting factors and suggestions it is apparent that the ideal height of the keyboard is individual specific and is primarily determined by the stature of the operator and the height of the seat pan plus their typing ability, which in turn affects their typing style, as these factors influence the neutral positions of various body segments. It is evident that not only the wrists and arms, but the entire body is affected by the position of the keyboard.

Several researchers proposed that relative to sitting height, a lower keyboard, which is tilted away from the user, promotes a neutral wrist posture when typing (Hedge *et al.*, 1999; Dowler *et al.*, 2001). Hedge and Powers (1995) indicated that this, together with a palm rest, is recognised as the negative slope keyboard support system. It is argued that a system of this nature reduces the postural risk for carpal tunnel syndrome as it

decreases wrist extension, and according to Fagarasanu and Kumar (2003) a negative slope increases the time spent by the wrist within the neutral zone by 60%. It also reduces the static load of the trapezius muscles thus enhancing user comfort. The negative sloping keyboard does, however, impede the typist's ability to view the keys and is thus unsuitable for users who are not able to touch-type (Fagarasanu and Kumar, 2003). These recent findings are in contrast to the "traditional" positioning of the keyboard where researchers such as Miller and Suther (1983) recommend a positive keyboard slope of $14° – 25°$ depending on hand size. They suggested that an increased keyboard angle shortens finger travel distance from the home row to the top row or space bar thus better accommodating those with small hands. They do, however, acknowledge the necessity for adjustability of slope in order to accommodate user variability and personal preferences.

Nakaseko *et al*. (1985) found that wrist and/or forearm supports lead to decreased medical complaints in the wrists, shoulders and back as they attempt to minimise perceived discomfort, musculoskeletal loads and carpal tunnel syndrome risk. More recent studies (Hedge and Powers, 1995; Aarås *et al.,* 1998) have, however, identified that wrist rests may actually be detrimental and increase the risk of CTDs. Aarås *et al.* (1998) point out that shoulder and neck muscle activity is increased with the use of wrist rests due to subjects raising their arms in order to avoid uncomfortable pressure on the underside of the wrist. Hedge and Powers (1995) indicated that the use of wrist rests elicit a similar response to resting the wrist on the work surface in that the pressure within the carpal tunnel was found to be elevated by an excess of 120%. This suggests that wrist rests are unsuitable for sustained typing tasks. Some researchers have proposed padded wrist rests to improve posture and decrease the pressure placed on the wrist, but Hedge *et al.* (1999) found that they had no effect on wrist posture. Hedge and Powers (1995) recommended palm rests rather be used to support the arms between bursts of typing as they would be more effective than wrist rests used during typing. Despite some negative findings, Hedge and Powers (1995) and Aarås *et al*. (1998) do recognise the need for some form of lower arm support in order to reduce musculoskeletal discomfort. They therefore suggested either forearm supports or full

motion supports which allow the forearms to rest in a mobile cradle which supports the arm weight for all horizontal movements, thus decreasing muscular activity in the neck and shoulders. Lintula *et al.* (2001) found that muscle load of the shoulders was decreased with the use of arm supports.

Besides the positioning of the keyboard, the last decade has seen numerous modifications in the design of the keyboard itself. In an attempt to reduce musculoskeletal loads and carpal tunnel syndrome risk, various new, and sometimes radical keyboards have been developed. According to Smutz *et al.* (1994) the traditional QWERTY keyboard (Figure 5) concentrates task duties on only a few fingers, and similarly Eggers *et al.* (2003) suggested that the arbitrary arrangement of letters without any alphanumeric logical order is not optimised according to a high hit rate. They proposed that the keyboard was in fact designed for mechanical typing machines and thus to slow typists down in order to prevent a mechanical linkage jam.

Figure 5: Traditional QWERTY layout.

The modern alternate keyboards, such as the DvortyBoard design (Figure 6) attempt to distribute the load adequately among more of the fingers. Eggers *et al.* (2003) found that newly designed keyboards aim to increase typing speed by reducing the number of times consecutive keys are hit with the same hand and more specifically the same finger, as this is thought to reduce typing performance. However, Gerard *et al.* (1994) pointed out that most computer operators are accustomed to the QWERTY layout and are unfamiliar with keyboards such as the DvortyBoard, and they are thus reluctant to relearn and adjust to a completely different keyboard.

Figure 6: DvortyBoard keyboard layout.

In terms of the various QWERTY keyboard designs, Kroemer (1972) proposed the use of the split keyboard design (Figure 7a) where the palms face medially while operating the keyboard thus maintaining a neutral wrist position and alleviating static wrist extension and ulnar deviation. According to Fagarasanu and Kumar (2003) the split keyboard results in ulnar deviation ranging from $7.0 - 8.5°$ for the left wrist and $2.7 - 5.0°$ for the right wrist compared to $15 - 30°$ for both wrists whilst operating the conventional keyboard. This keyboard is, however, not widely used due to its radical design. Hobday (1988) recommended a slightly modified version of the split keyboard with a substantially less radical design known as the Maltron (Figure 7b). The keys in this keyboard were designed so that the thumbs could become more active and the key set is contoured in order to accommodate changes in finger length. However, Hedge and Powers (1995) reported that these two designs only alleviate ulnar deviation, and not wrist extension. Use of the Kinesis keyboard (Figure 7c) was analysed by Gerard *et al.* (1994). This keyboard has built-in forearm supports to decrease the musculoskeletal load, and thumb operated keypads in order to redistribute some of the workload from the little finger to the thumbs. Hedge and Powers (1995) support use of the Kinesis keyboard as opposed to the conventional keyboard as it reduces ulnar deviation from $20°$ to $9°$ and eases wrist extension from $20°$ to $12°$. Although these operating postures are not completely neutral, the Kinesis keyboard offers the best arm/hand configuration suggested thus far. Even though these ergonomically designed keyboards may have a high initial cost, it is argued that they will reduce further health costs (Fagarasanu and Kumar, 2003).

| a. Split Keyboard | b. Maltron Keyboard | c. Kinesis Keyboard |

Figure 7: Ergonomically designed keyboards.

Due to the excessive use of the keyboard and concomitant high incidence of CTDs, other means of data entry are being investigated. One way to avoid the risk of CTDs associated with the use of keyboards is the use of a completely different data input method altogether. Amell and Kumar (1999) identified light pens and speech recognition software as a means of data entry. They do, however, caution that these alternatives may result in further ergonomics concerns. Such concerns may include voice problems if natural continuous speech is not permitted, or musculoskeletal overuse injuries or neurological conditions associated with light pens.

Mouse position

Keir *et al.* (1999) described the computer mouse as an important data input device which has created new problems in today's workplace. Second to the keyboard the mouse is the most commonly relied on input device and dependence on it is increasing since contemporary software packages have a far greater demand for mouse use than previously. Fernström and Ericson (1997) did, however, point out that it is possible to use the keyboard as the sole data input device, but this is seldom the case as the commands required to use the keyboard exclusively present a relatively high cognitive load since their structure is inconsistent and not logically related to the task (see Table I).

Table I: Examples of when the keyboard can be used in place of the mouse.

Press	To
CTRL+SHIFT+F	Change the font
CTRL+SHIFT+>	Increase the font size
CTRL+SHIFT+<	Decrease the font size
CTRL+SHIFT+A	Format letters as all capitals
CTRL+SHIFT+K	Format letters as small capitals
CTRL+B	Apply bold formatting
CTRL+U	Apply an underline
CTRL+SHIFT+W	Underline words but not spaces
CTRL+I	Apply italic formatting
CTRL+EQUAL SIGN	Apply subscript formatting
CTRL+SHIFT+PLUS SIGN	Apply superscript formatting
CTRL+1	Single-space lines
CTRL+2	Double-space lines
CTRL+5	Set 1.5-line spacing
ALT+CTRL+1	Apply the Heading 1 style
ALT+CTRL+2	Apply the Heading 2 style

Atkinson *et al.* (2004) indicated that the increased use of the mouse may be the reason for the concomitant rise in the intensity of discomfort and the frequency of neck, shoulder, arm and hand musculoskeletal disorders as a result of the unnatural posture in which the shoulder and wrist are placed during mouse use. Fagarasanu and Kumar (2003) recognised that the lateral position of the mouse is due to the original workstation design that only took the keyboard into consideration. Because of its location, Cook and Kothiyal (1998) found that mouse use required unilateral shoulder flexion, abduction and external rotation and they suggested that it is this sustained shoulder posture that leads to discomfort and pain symptoms in the neck and trapezius.

Harvey and Peper (1997) proposed that the position of the mouse may be a critical factor in determining the extent of shoulder flexion and abduction, and resultant strain on the deltoid and trapezius muscles of the neck-shoulder complex. Several researchers (Fernström and Ericson, 1997; Cook *et al.*, 2000) concur that the mouse should be located as close to the operator's midline as possible since they found that when the

mouse was operated further to the right of the midline there was an increase in muscle tension in the trapezius and the right deltoid as well as the forearm and back musculature due to increased flexion and abduction of the right shoulder. Lintula *et al.* (2001) recommended the use of mobile arm supports during mouse work in order to decrease the muscle strain experienced in the shoulder.

In terms of shoulder posture, shorter keyboards, such as those without number pads, are superior as they enable the mouse to be located closer to the middle. Although Gilad and Harrel (2000) identified broader shoulders to be detrimental in terms of the optimal wrist posture with keyboard use, these individuals have a substantially lower degree of shoulder abduction while operating the mouse. In terms of the height of the surface upon which the mouse is operated, Cook *et al.* (2000) recommend that it not be too high as this may worsen the shoulder posture by encouraging shoulder elevation. Dowler *et al.* (2001) demonstrated that together with static muscular tension, prolonged shoulder elevation produced considerable pain in computer operators.

Wrist extension and ulnar deviation has been reported during computer mouse use (Karlqvist *et al.*, 1994; Cook and Kothiyal, 1998). Gilad and Harrel (2000) identified the natural wrist posture as being less than 15° of wrist extension with less than 20° of ulnar deviation, yet Karlqvist *et al.* (1994) have reported cases of wrist extension of up to 30° and ulnar deviation exceeding 40° with the forearm in a pronated position. According to Werner *et al.* (1997) wrists maintained in these unnatural postures lead to an increase in the intracarpal pressure which places the individual at a higher risk of developing carpal tunnel syndrome. Keir *et al.* (1999) pointed out that carpal tunnel pressure during active mouse use often reaches levels of concern (above 30 mmHg), which if prolonged will lead to nerve damage in that region. Furthermore, Fagarasanu and Kumar (2003) revealed that approximately 25% of computer operators use their non-dominant hands for mouse control. Although the settings can easily be changed so that the mouse is positioned to the left of the keyboard, very few users do so. The result is awkward postures and a high prevalence for carpal tunnel syndrome. In addition recent research has shown that a mouse used to the left of the keyboard reduces shoulder abduction by

8° and shoulder flexion by 7° because of the dimensions of the keyboard, thereby diminishing the postural constraint by introducing left hand mouse use (Delisle *et al.*, 2004).

Keir *et al.* (1999) also reported that the fingertip forces required to press the mouse buttons and the pinch forces on the sides of the mouse contribute to the intracarpal pressure. These authors suggested that tasks which involve dragging as opposed to pointing with the mouse require that the mouse button be depressed for longer and the pinch forces are three times greater. Freivalds (2003) noted that dragging tasks therefore resulted in a carpal tunnel pressure of 33.1mmHg as compared to 5.3mmHg during a neutral resting state. Dragging tasks should thus be minimised in order to reduce the risk of carpal tunnel syndrome in computer mouse users. Furthermore, according to Fernström and Ericson (1996) all repetitive mouse tasks requiring a high level of accuracy and/or precision, whether pointing or dragging tasks, increase the risk of developing neck and shoulder disorders.

Workstation interventions

Aarås *et al.* (1997) investigated the use of a forearm support to place the wrist in a more neutral position. The results revealed a decrease in the trapezius activity and a similar reduction in the load of the erector spinae. Fernström and Ericson (1997) also found that the forearm supports reduced the load of the shoulder, but they showed that the strain of the forearm and hand was increased without any significant decrease in the carpal tunnel pressure.

Several variations in the design of the mouse have been developed with the intention of improving wrist postures. Keir *et al.* (1999) assessed three different computer mouse designs. They found no differences in wrist posture or carpal tunnel pressure between the designs. Contrary to this, Aarås *et al.* (2002) found that the Anir mouse (Figure 8) places the forearm in a more neutral posture by reducing the amount of pronation. It also allows for a reduction in wrist extension and ulnar deviation. As a result discomfort and pain in the neck, shoulder, forearm and hand/wrist was reduced.

Figure 8: Ergonomically designed Anir mouse.

Another possible solution put forward by Harvey and Peper (1997) is the use of a trackball located centrally within the keyboard as opposed to the mouse. They found that compared to the computer mouse this device reduced tension in the back, shoulder and arm musculature. However, Fernström and Ericson (1997) discovered that the central trackball actually increases the load of the forearm since it increases wrist extension by at least 6°, and more recently Fagarasanu and Kumar (2003) established that radial deviation ranged between 2 – 7° while using a trackball, as opposed to the mouse which forces the wrists into 5 – 15° of ulnar deviation. Instead of altering the device, Fernström and Ericson (1997) emphasised the need to vary one's working posture in order to decrease the risk of acquiring cumulative trauma disorders associated with extensive computer mouse use. Similarly Aarås *et al.* (2002) recommended that intensive mouse users alternate between several different mouse devices in order to vary muscle activity.

HUMAN FACTORS

Anthropometric factors

The physical characteristics and dimensions of the individual operator should be taken into account when designing objects and environments for human use. Bhatnager *et al.* (1985) recognised the importance of applying anthropometry to the design of workplaces in order to allow the user to maintain neutral working postures thereby minimising musculoskeletal complaints, reducing perceived discomfort and increasing safety.

Ong *et al.* (1988) caution that computer workstations in industrially developing countries are often imported from developed countries. These imported workstations have been designed for the specific morphology of the local population and because of the different anthropometric dimensions of the two user populations, they will probably pose numerous musculoskeletal problems for the countries into which they have been imported. This highlights the importance of taking cognisance of geographical and ethnic differences in workstation design.

In a study done by Grandjean *et al.* (1983) they found that preferred workstation settings were not noticeably influenced by anthropometric data after calculating correlation coefficients for screen heights and eye levels above the floor, and for keyboard heights and body length. However, this study allowed subjects to decide what their preferred settings were without any habituation time at other possibly more suitable settings. As a result subjects may simply have chosen settings similar to those which they were used to. Nevertheless, Grandjean (1987) suggested that the various workstation dimensions should be adaptable to suit several elements of body size in order to allow for comfort and suitable working postures. Adjustable placement of the monitor and keyboard give the user freedom to adjust the workstation configuration for maximal comfort.

Acknowledging the importance of taking cognisance of human variability, Secrest and Dainoff (1984) suggest that if the chair, keyboard height and screen height are adjusted according to each individual's anthropometric characteristics, the operators will be able

to attain postures such that their feet are flat on the floor, their lumbar region is fully supported, their wrists are anatomically neutral, their neck posture is optimal and their visual requirements are accommodated.

Perceived discomfort

Corlett and Bishop (1976) defined discomfort as a warning provided as an indicator of the inadequacy of the compatibility between the people and their work. Reports of discomfort, therefore, indicate the need to adjust the job or workplace to suit the operator, rather than expecting the operator to adapt to the workstation. It is evident that the background to discomfort is complex and a holistic and multidisciplinary approach may therefore be required in order to identify work situations inducing musculoskeletal pain and discomfort. Musculoskeletal discomfort is generally the result of several factors including physical, psychosocial and individual factors (Smith, 1997), and which among computer operators is a recognised problem which can be avoided, or at least significantly reduced.

Physical factors

Helander and Zhang (1997) described feelings of discomfort as being associated with pain, tiredness and numbness which are assumed to be imposed by physical constraints in the design of the workstation. The prolonged nature of computer work with repetitiveness, associated static loads, and restricted and awkward postures results in strain being experienced within the musculoskeletal system, which Evans and Patterson (2000) report to be associated with higher ratings of perceived discomfort.

Computer work involves small repeated movements of the arm and hand, which according to Jensen *et al.* (2002a) involve a large component of static loading on the shoulder and lower arm muscles. These static loads, together with those placed on the neck, back and lower extremity, result in low level muscle activation, reduced blood flow to the muscle and oedema, which several researchers suggest to be directly related to discomfort (Winkel and Jørgensen, 1986; Sauter *et al.,* 1991). Solutions proposed to alleviate these problems are to bring in task diversity, with more work tasks requiring

greater physical involvement being incorporated, and, as recommended by Aarås *et al.* (1998), frequent rest breaks in order to prevent the build up of discomfort.

In terms of working postures Mekhora *et al.* (2000) and Aarås *et al.* (2002) reported that changes towards more neutral postures result in reduced muscular load thereby improving circulation and enhancing the removal of waste products from the muscle. This together with the improved muscle nutrition results in a reduction in discomfort and fatigue. Fagarasanu and Kumar (2003) point out that a person chooses a particular working posture because they feel the position is most appropriate in relation to the task and workplace. However, this posture is often different to an ergonomically correct posture because the task or workstation requires adoption of hazardous postures. It is therefore necessary to adjust the workstation in order to allow more neutral working postures.

Psychosocial factors
Although there is reduced physical exertion required in computerised job situations, there is a concomitant increase in the mental demand placed on the employees. Smith (1997) pointed out that compared to traditional office jobs, modern computerised jobs are more sedentary, require more cognitive processing and mental attention, and are more focused on time as an important resource. Production demands of such jobs are often high and result in constant work pressure. Several studies (Hales *et al.*, 1994; Smith, 1997) have suggested that high levels of mental stress associated with increased pressure, workload and task difficulty, together with the fear of losing one's job are factors that increase the level of anxiety, muscle activity and muscle tension. This is a result of elevated sympathetic hormonal production because of the psychological stress, which thereby has a direct influence on musculoskeletal pain and discomfort, especially in the neck and shoulder regions. According to Jensen *et al.* (2002b) other psychosocial risk factors include low influence over the job, minimal control, few possibilities for development at work and lack of supervisor or colleague support. Jensen *et al.* (2002a) argued that there is a strong relationship between psychosocial and physical factors,

and found that respondents with more repetitive movements and work tasks were more prone to report low job control.

Mekhora *et al.* (2000) reported that it is possible for subjects to be positively psychologically influenced when placed in an ergonomically designed workstation due to a sense of it being superior. They also suggested that subjects may be affected by the study itself since they tended to respond by adapting themselves to a more erect, upright posture.

Individual factors

Because of the uniqueness of individuals, with all else being equal, one cannot expect any two computer operators to experience or perceive discomfort in the same way. Mekhora *et al.* (2000) found that ratings of discomfort varied between individuals due to varying discomfort thresholds. In addition Helander and Zhang (1997) cautioned that measures of discomfort are not always accurate reflections of the workstation design since people often subconsciously adjust their postures before the onset of noticeable discomfort thus reducing any build up of pressure and preventing discomfort.

Karlqvist *et al.* (2002) also identified anthropometric variations as a possible contributing risk factor. They found that narrow shouldered people experienced more shoulder discomfort because the mouse had to be used in a non-optimal location where shoulder flexion and abduction was greater than for a broad shouldered person. However, these broad shouldered operators may experience more wrist or forearm discomfort since their wrists are forced into greater ulnar deviation while operating the keyboard.

Benefit of implementing changes

Duration of computer work is positively associated with level of discomfort. According to Bhatnager *et al.* (1985), as working time increases so computer operators tend to lean forward more; they also change positions more often, perceive more discomfort and their standard of performance declines. However, they did caution that there is a belief that making workers "too comfortable" will induce drowsiness and reduce productivity. It

is therefore important to investigate both discomfort levels and standard of performance. Corlett and Bishop (1976) defined discomfort as a concept with a threshold below which the operator would not be distracted from his work. Numerous studies have shown that increased comfort allows for enhanced performance (Corlett and Bishop, 1976; Carter and Banister, 1994; Karlqvist *et al.*, 2002).

Musculoskeletal discomfort is often simply resolved by rest. However, if the underlying cause of discomfort is not investigated and improved there is a risk that the discomfort will progress to a disabling musculoskeletal disorder (Carter and Banister, 1994). The direct and indirect costs associated with such a disabling condition are likely to outweigh those involved in improving the computer workstation before musculoskeletal disorders occur. After making adjustments to the workstation, a period of familiarisation is required before benefits will be recognised. Aarås *et al.* (1998) found that the initial implementation of a workstation design based on ergonomic principles often led to an initial increase in ratings of discomfort followed by a reduction as they became accustomed to the new design over time.

Cumulative trauma disorders

Prolonged work while experiencing discomfort as a result of poorly designed computer tasks and workstations increases the risk of developing cumulative trauma disorders, which, according to Yassi (1997), are generally related to joints, ligaments, tendons or muscles, as well as some common peripheral nerve entrapment and vascular syndromes, which ultimately prevent the employee from being able to continue with the task. Ming and Zaproudina (2003) found that intensive computer use is associated with a greater risk of neck, shoulder, elbow and hand numbness and pain. Carter and Banister (1994) indicated that these symptoms are also observed in the back and lower extremity.

Although work-related musculoskeletal disorders have been occurring for many years, Yassi (1997) reported that their occurrence is increasing. This is party attributable to improved recognition and reporting, but also because work has become more

segmented and therefore repetitious, and there is an increase in mechanisation and rapid pacing of work in a stressful and highly competitive global economy (Yassi, 1997). Similarly Balci and Aghazadeh (2003) found that the number of CTDs, as a percentage of total illness reported to the Occupational Safety and Health Administration (OSHA), was 18% in 1981 and 52% in 1992, and according to the Bureau of Labour Statistics in 2000 it was 67%. Fagarasanu and Kumar (2003) argued that there are numerous factors which are important in the development of CTDs, some of which include repetition, static work and awkward postures.

Repetitive movements

Cail and Aptel (2003) indicated that the repetitive nature of computer work, such as typing and using the mouse, is a risk factor for CTDs. The muscles that control the movement become irritated and fatigued and the soft tissues become inflamed and swollen. Tendons can also swell as a result of the friction caused by the tendons sliding over one another, thus leading to painful tendonitis such as DeQuervain's syndrome (Ming and Zaproudina, 2003). The irritated muscle, swollen tendons and soft tissues can put pressure on nerves and lead to ischemic neurophysiological changes. This results in a progressive reduction in nerve conduction causing numbness, tingling and, in advanced cases, reduced coordination, loss of strength and pain. An example of such a disorder is carpal tunnel syndrome.

Static postures

Operating a computer for an entire working day requires fairly static working postures. This is especially evident in the head and neck; Ming and Zaproudina (2003) note that viewing the computer screen and maintaining the head's static posture results in the neck and shoulder muscles becoming overworked, and eventually the development of a strain injury. According to Aarås *et al.* (2002) long lasting activity of single muscle fibres may overload their capacity and start a damaging process. This is further explained by Kadefors and Laubli (2002) who argued that low-threshold motor units are always recruited as soon as a muscle is activated, and remain active until there is total muscular relaxation. With prolonged static muscle activation there is a lack of recovery, resulting

in metabolic overload at the membrane level, which causes a degenerative process leading to cell damage, pain and necrosis. Thorn *et al.* (2002) demonstrated that although there is some substitution of motor units, there are low-threshold motor units which are continuously active during low-level, long-duration static work. They did, however, state that it is unknown as to the length of time motor units can remain active before damage to the fibres occurs, and also the duration of rest periods required between bouts of activity to avoid damage.

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                    ┌──────────────┐
                    │ OTHER CAUSES │
                    └──────────────┘
┌───────────────┐          │              ┌───────────────┐
│ MENTAL STRAIN │          │              │ IMMOBILISATION│◄──────┐
└───────────────┘          ▼              └───────────────┘       │
         │          ┌─────────────────┐          │               │
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                    │ INFLAMMATION │                         │    │
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     ┌──────────────┐        ┌─────────────────┐             │    │
     │ MESENCHYMAL  │        │ PAIN/DISCOMFORT │             │    │
     │TRANSFORMATION│        └─────────────────┘             │    │
     └──────────────┘                                        │    │
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                    ┌──────────────┐                         │    │
                    │MUSCULOSKELETAL│────────────────────────┘    │
                    │  DISORDER    │──────────────────────────────┘
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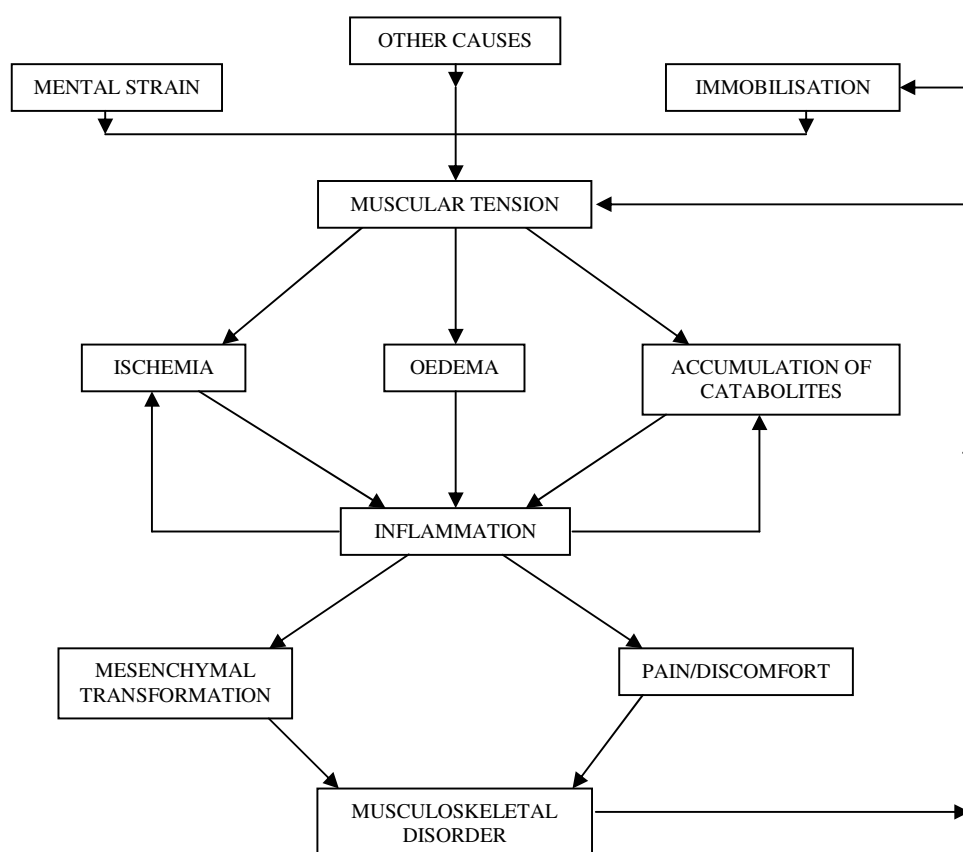
Figure 9: Factors influencing the development of musculoskeletal disorders.

(Modified from Grieco, 1986).

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The development of musculoskeletal disorders is similar for static postures caused by both physical and psychological factors. Grieco (1986) stated that prolonged static loads cause an increase in endomuscular pressure, relative constriction of the blood vessels and consequent ischemia. The result is a reduced supply of nutrients to the muscle and accumulation of energy metabolites. This then leads to inflammation and pain and finally functional impairment, which maintains the process since it leads to further immobilisation and muscular tension (see Figure 9).

Awkward postures

The risks associated with repetitive work and static postures are exacerbated by awkward or unnatural working postures which, as Mathiassen *et al.* (2003) point out, lead to unfavourable patterns of muscle activity. According to Kumar (2001) such postures lead to compression of the microstructures and elevation of the force requirements of the task thereby contributing to muscle tendon inflammation. Carter and Banister (1994) reported that when a monitor is placed in an inappropriate position, such that the neck is flexed, the static load experienced by the neck muscles in order to hold the head in position is increased substantially. Furthermore typing with wrists in excessive extension and/or ulnar deviation elevates the pressure within the carpal tunnel as a result of inflammation of the tendons and their sheaths (Sanders and McCormick, 1992). Werner *et al.* (1997) noted that when wrists are extended, flexor tendons and the median nerve are stretched, and according to Fagarasanu and Kumar (2003) the tendons are displaced against the dorsal side of the carpal tunnel and the head of the radius thus resulting in high pressure being exerted on the tendons. These factors all contribute to the high risk of developing carpal tunnel syndrome. Fagarasanu and Kumar (2003) did, however, caution that when adjusting the workstation to modify an unnatural joint angle, other joints may be forced into extreme angles. An example being when reducing the wrist extension and forearm pronation associated with keyboard use, the arm could be forced into prolonged abduction, which these authors recognise as being a major risk factor for rotator cuff tendonitis.

Not all keyboard users are at high risk of developing carpal tunnel syndrome, and it is important to consider the operators' typing ability when assessing their carpal tunnel syndrome risk. Fagarasanu and Kumar (2003) indicated that because non-touch typists usually rely on the strongest fingers, being the index and middle fingers, and because their forearms are poised in midair above the keyboard they do not experience wrist fatigue or maintain postures of ulnar deviation, and as a result they are at a lower risk of developing carpal tunnel syndrome.

As Armstrong *et al.* (2003) comment, it is when workstation dimensions and/or job requirements are not suited to operator morphology and/or capabilities that a reduction in performance efficiency and increased likelihood of musculoskeletal symptoms occur. It is of utmost importance to implement sound ergonomic interventions to computer workstations before musculoskeletal symptoms reach a state of chronic cumulative trauma disorders, because as Aarås *et al.* (2002) indicate, once the symptoms have become chronic they are very difficult to cure, even if the worst risk factors are reduced to a minimum.

Electromyography

Rodahl (1989) pointed out that the contraction of muscle fibres is associated with small electrical changes within the muscle. Electromyography (EMG) involves the recording of these myoelectric signals which occur when a muscle is in use, giving an indication of the exerted muscle force (Corlett, 1990). According to Rodahl (1989) EMG reflects the magnitude of muscle engagement and is often used to measure the exerted force as a percentage of maximum voluntary contraction (MVC) which enables both interindividual and intraindividual comparisons to be made. MVC is measured prior to testing, but as Fernström and Åborg (1999) warn, pain or injury of that muscle may impact on an accurate MVC recording.

For static work, such as that associated with computer work, Rodahl (1989) cautions that the 100% of maximum can only be maintained for a few seconds, 50% of MVC for approximately one minute, and less than 15% of MVC from 10 minutes up to a few

hours, depending on the individual. Rodahl (1989), however, recommended that for indefinite static work, muscle activity levels should be less than 10% of MVC, and in a recent study by Thorn *et al.* (2002) it was demonstrated that work-related musculoskeletal injuries occur even when static work muscle activity levels are less than 5% of MVC.

EMG can be used to determine the onset of muscle fatigue, which occurs when a muscle is unable to maintain a required force of contraction. Fatigue is identifiable through the characteristic changes in muscle activity. Corlett (1990) has shown that the onset of fatigue causes an increase in amplitude in the low frequency range and a decrease in amplitude in the high frequency range. There is also a shift in the frequency spectrum towards the lower end of the spectrum.

High levels of muscular activity may indicate an elevated risk of musculoskeletal disorder development (Straker and Mekhora, 2000). The use of EMG could therefore be very useful in the design and assessment of computer workstations. In terms of monitor placement Straker and Mekhora (2000) did, however, suggest that muscle activity may be minimal when the head and neck are in extreme postures because passive connective tissues take more of the load. Several studies have shown that although the EMG recordings for the trapezius muscles did not change when the monitor height was adjusted, that of the cervical erector spinae showed a significant reduction in muscle activity when the monitor was raised (Villanueva *et al.*, 1997; Straker and Mekhora, 2000; Seghers *et al.*, 2003). Fernström and Åborg (1999) warn that changes in workstation design have to be extensive in order to influence mean muscle activity sufficiently enough for it to be evident on an EMG recording.

TASK DEMANDS

Mekhora *et al.* (2000) noted that recommendations made for the design of computer workstations are often generalised and should in fact be specific to a single work task and a particular individual. There are several different tasks for which people interact

with computers, and all of these place different demands on the operator, and therefore need to be considered individually. Supporting this argument, Ibbotson *et al.* (2003) suggest that the use of input devices differ depending on the task or environment for which they are employed. Therefore, characterisation of specific tasks and jobs may lead to more accurate and specific exposure assessments, which in turn should assist in reducing the risk of developing work-related musculoskeletal disorders.

Ibbotson *et al.* (2003) identified three categories of computer related work tasks. These include data entry, data retrieval and text editing. Data entry involves the continuous input of information into the computer. Gao *et al.* (1990) pointed out that numbers, words and/or symbols are read from the source documents and then entered into the computer via the keyboard. Operators sometimes use only the right hand to operate the keyboard, while the left hand handles the source documents. Finally the operator looks at the screen to check that no errors have been made. This mode of work is monotonous and repetitive and often results in constrained working postures and a considerable amount of discomfort in the neck, shoulders, arms and wrists (Gao *et al.*, 1990)

According to Cail and Aptel (2003) both Computer Aided Design (CAD) and data retrieval require that the operator's gaze be directed mainly at the screen and sometimes at the keyboard and source documents. Unlike data entry tasks where the keyboard is the main input device, these tasks are highly dependent on the mouse and as a result the left hand is often not in use.

During text editing tasks the gaze is directed primarily at the screen and if applicable, the source documents. The operator relies on the mouse to position the cursor in the correct place for editing, and the keyboard is used to alter the data (Ibbotson *et al.*, 2003).

It is evident that the physical demands of work tasks differ and need to be considered. For example, while the optimal placement of the keyboard is fundamental to the reduction of discomfort for data entry employees, the design and position of the mouse would possibly be more relevant for data retrieval tasks and CAD. However, there are

also several psychosocial factors relating to specific tasks which also need to be considered. Jensen *et al.* (2002b) emphasise that risk factors such as high work demands, low decision-making and low possibilities for development at work are present for some tasks, such as data entry, yet not for others.

PERFORMANCE EFFICIENCY

Adjusting a computer workstation to allow for more neutral working postures will not only improve comfort and decrease the risk of developing CTDs, but it is also likely to enhance operator efficiency. A study by Blyth *et al.* (2003) demonstrated that most people experiencing chronic pain continue to work despite the pain. However, the majority of these pain sufferers reported some reduction in work effectiveness as a result of the pain.

According to Pheasant (1996) performance efficiency can be assessed by evaluating work output per unit time and/or error rate. He indicated that mounting levels of discomfort might distract the operator thus leading to a sub-optimal level of concentration and a reduction in performance efficiency. In addition to this, if the mental or physical load placed on the operator is increased, the operator is forced to devote more resources to coping with this demand. If this condition is ongoing, the result will be chronic mental and physical strain, as well as a diminished performance capability (Secrest and Dainoff, 1984). These authors found a definite improvement in work output when operators were placed in conditions of greater comfort.

In terms of monitor, keyboard and mouse placement, these components should be positioned at levels whereby the postures of the operators will be most natural, as this will reduce the level of discomfort and ultimately improve performance efficiency. Carter and Banister (1994) did, however, caution that although ergonomic changes to a workstation may enhance comfort and improve performance, they may cause other musculoskeletal disorders. For example, by enabling faster typing speeds the risk of

developing carpal tunnel syndrome may be greatly increased by the higher level of repetition.

INTERVENTIONS

An attempt to reduce the negative consequences of computer use has been made through the introduction of interventions which are structured around ergonomically based recommendations (Mekhora *et al.*, 2000). According to Das and Sengupta (1995) ergonomic interventions for computer workstations take into consideration posture, spatial accommodation, reaching abilities, clearance and interference of body segments, field of vision, available strength of the operator and biomechanical stresses. These recommendations focus on adjusting the physical components of the workstation to suit the users' morphological characteristics in order to reduce musculoskeletal discomfort and work-related disorders. However, there are several other interventions which can be implemented together with the physical workstation adjustments.

Task diversity

As pointed out by Golding (1988) traditional office jobs required the employee to perform a variety of physical and mental activities. The exponential increase in the number of computer-based office jobs has led to a growing number of static work postures where the employee focuses on the computer screen and source documents and they operate a keyboard and mouse with their hands. With this increased use of computers there has been a concomitant increase in the number of work-related musculoskeletal disorders.

Fernström and Åborg (1999) found that a lack of alternative tasks offering a different exposure pattern during work hours resulted in an elevated risk for shoulder-neck complaints. They therefore suggested that a lack of variation in muscle activity may increase the likelihood of fatigue and discomfort, and recommended that work tasks be altered during the day, with new tasks providing changes in movements and pace as well as muscular load in order to prevent musculoskeletal discomfort and disorders. Kadefors and Laubli (2002) and Karlqvist *et al.* (2002) concur that computer operators

with less variability in work tasks perceive a higher degree of job strain and experience more musculoskeletal problems associated with computer work.

Rest-breaks

It has been strongly argued that the duration of continuous computer use is directly related to the risk of developing work-related musculoskeletal disorders (Galinsky *et al*., 2000; Blatter and Bongers 2002; Hayashi *et al*., 2004). Balci and Aghazadeh (2003) urge that the work environment be adjusted by introducing a work-rest schedule which is easily applicable, inexpensive and advantageous for reducing computer related problems. They indicated that a work-rest schedule produced significant reductions in neck, shoulder, upper and lower back, chest and elbow/arm discomfort, eyestrain, blurred vision, as well as enhanced performance efficiency.

Although these may be disruptive to task activities, the general consensus is frequent, short breaks. According to Balci and Aghazedeh (2003) 15 minutes work followed by a microbreak resulted in a significantly enhanced performance and lower levels of discomfort. However, 30 minutes work followed by 5 minutes rest resulted in the lowest eyestrain and the least blurred vision. Kopardekar and Mital (1994) demonstrated that 30 minutes work followed by 5 minutes rest resulted in fewer errors than 60 minutes work followed by 10 minutes rest. Furthermore Bhatnager *et al.* (1985) pointed out that discomfort and heart rate were lowest after a rest-break compared to at the end of a 25-minute work period. They therefore recommended a rest-break every 25 minutes. Yassi (1997) suggested stretching exercises in some of the work-breaks, as this increases blood flow to the muscles thereby minimising musculoskeletal discomfort.

Biofeedback

Harvey and Peper (1997) noted that the people at greatest risk for developing upper extremity musculoskeletal disorders (UEMSDs) are probably unaware of muscle tension and do not release this tension with the use of microbreaks or large movement breaks. They therefore suggested the use of surface electromyography biofeedback training in order to develop the individual's subjective awareness of muscle tension, thereby

reducing the risk of UEMSDs. According to Gerard *et al.* (2002) EMG biofeedback has been shown to reduce EMG levels by alerting the individual when muscle activity reaches a certain level and thus encouraging them to release the tension. They also note that similar auditory feedback has been used to decrease excessive keying force while typing. Visschers *et al.* (2004) have recently investigated an on-screen computer warning system to help reduce CTD risk and they found that this form of feedback significantly improved the working postures of computer operators.

COST-BENEFIT OF ERGONOMICS CHANGES

Although the well-being of the workers is important, Carter and Banister (1994) noted that managers are also concerned about the economic cost-benefit of implementing ergonomic improvements to the workplace. Managers tend to focus on financial issues and are interested in whether, without initiating workstation modifications, the discomfort will progress to a disabling occupational disorder, what direct and indirect costs associated with such a disorder will be, and whether ergonomic improvements will lead to improved productivity.

According to Carter and Banister (1994) not all discomfort progresses to a disabling condition, as in some cases it is resolved simply by rest and/or task diversity. However, Kumar (2001) reported that although the human body is able to recover from stress exposure, a prolonged period of repeated exposure may limit total recovery because the adaptive ability is insufficient to offset the biomechanical stress factor. An accumulation of such residual strain reduces the body's stress tolerance capacity thus increasing its susceptibility to injuries. Similarly Karlqvist *et al.* (2002) suggested that a well designed computer workstation with sound ergonomic principles is important in avoiding musculoskeletal disorders, and for improving comfort, productivity and quality of work.

There are a several factors which contribute to the costs involved in work-related injuries. Fagarasanu and Kumar (2003) suggest that although workstation modifications may have high initial costs, if done initially these modifications may reduce the future

medical and non-medical costs of the company. They reported that 6% of carpal tunnel syndrome patients require life-long medical treatment, which is a huge cost that could possibly be prevented.

An indirect cost associated with occupational injuries is lost productivity. Blyth *et al.* (2003) assessed the impact of working with pain which reduced effectiveness of work performance, and found that cost of lost productivity was more than three times that associated with the number of work days missed. Fagarasanu and Kumar (2003) draw attention to further indirect costs which include compensation settlements and disability payments, plus the replacement of injured employees. Whether these are of a temporary basis, while the employee recovers, or whether the problem is of a more permanent nature, there are costs associated with the training of temporary staff and lost productivity during that training time since they will not be as productive as someone that is already trained. Koningsveld *et al.* (2003) also note that these untrained temporary staff are more likely to make mistakes, which in the case of some companies may lead to the loss of clients. Amell *et al.* (2002) argued that ergonomics input, specifically in the design of workstations, is an opportunity for substantial cost reduction within the company because in many cases occupational injuries are preventable. If ergonomic principles are considered in the planning stages, one not only prevents the development of these injuries but, as reported by Mekhora *et al.* (2000), one avoids the huge costs required to replace workstations in workplaces where poorly designed workstations are already installed.

It is in a company's best interest to ensure the correct design of their computer workstations as this will improve worker comfort and in doing so will reduce the risk of developing cumulative trauma disorders, which are associated with numerous direct and indirect costs. It will also enhance performance efficiency thus ultimately improving productivity.

CHAPTER III
METHODOLOGY

INTRODUCTION

According to Smith (1997) computerised jobs in general are highly sedentary, require a large amount of mental attention and cognitive processing, and demand only a small amount of physical energy to be expended. These cognitively demanding and physically restrictive work requirements are compounded by the relatively static, unnatural working postures employees are required to maintain for extended periods. In addition, the repetitive nature of typing is an important factor to be considered. The combination of the two impose a great risk of musculoskeletal problems on the user. It is well recognised that the cumulative risk factors associated with the task demands of a computer operator can be reduced by establishing an optimal design of computer workstations to suit the physical characteristics of each individual user. This highlights the importance of personalised computer workstations. Mekhora *et al.* (2000) pointed out that more neutral working postures lead to a reduction in muscle activity and the load and moments placed on the body segments. As a result there is not only a reduction on musculoskeletal strain, but there is also a concomitant improvement in circulation, thereby enhancing the removal of waste products from the muscles and increasing their nutritional status. Consequently there is a reduction in both discomfort and fatigue and ultimately in musculoskeletal problems.

Computer operators of varying statures are frequently expected to work at computer workstations where the dimensions are identical for all users, and adjustability is often very limited. As a result operators are forced to adopt unnatural working postures in order to "fit" these sub-optimal workstation designs. The aim of this study was therefore to test the biophysical, physiological and perceptual responses, as well as performance efficiency of operators of varied stature at an average workstation with limited adjustability; then to personalise a workstation according to each subject's morphology and to retest the subjects in order to assess what effect a personalised computer

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workstation has on the various responses. Subjects were tested at a third workstation which was set up similarly to the personalised workstation with the addition of a custom-designed 'floating' wrist support. The aim was to determine whether such a support might further enhance the users' responses within a personalised workstation.

PILOT STUDY

Prior to conducting the experimental investigation, several preliminary studies were conducted in an Ergonomics Laboratory at Rhodes University. Computer workstation layout for the personalised workstation was investigated and appropriate electromyography sampling frequency and electrode placement were established. The ideal position of the digital video camera was also determined during these preliminary studies. The computer based performance test was completed by several subjects to ensure that it was of a sufficient duration for subjects with moderate variation in keyboard and mouse skills, and to standardise the battery of computer tasks used to assess performance efficiency. These pilot sessions provided insight into the most beneficial testing protocol and ensured experimenter familiarity with the equipment to be used. The responsibilities of the assistants were also established and practised during pilot testing (see Appendix A).

EXPERIMENTAL DESIGN

Workstation design

Subjects were tested at three different computer workstations. Condition 1 was an "Average Standard" workstation (A), while Condition 2 was a "Personalised" workstation (P) adjusted specifically for each subject. The third test condition was the same "Personalised" workstation used in Condition 2 with minor adjustments to accommodate the addition of a "wrist support" (WS).

In a previous study by Scott *et al.* (2003) the dimensions of three Rhodes University computer laboratories were assessed, an example of which is illustrated in Figure 10. All

three of these laboratories had limited room for adjustability. The mean dimensions (Table II) of the basic workstations of each of these laboratories were used as the basis to set up the computer workstation for Condition 1 in order to assess the operators' responses to an Average Standard workstation.

Figure 10: Example of a Rhodes University computer laboratory.

Table II: The values used as a baseline to set up the Average Standard workstation.

	Mean	SD
Desk height (mm)	771.3	30.0
Monitor height (mm) (Centre of screen from desk)	367.0	17.7
Keyboard height (mm) (from ground)	787.7	31.8
Seat height (mm)	501.2	34.4

In Condition 2, with the Personalised workstation, selected components were adjusted to suit each individual. The chair in this workstation was adjusted in order to ensure a natural seated working posture. As Pheasant (1996) suggested, a 90° angle at the knee was achieved by either raising or lowering the chair, or by introducing a footrest should lowering the chair cause the desk surface to be too high. The centre of the monitor was raised to eye level and the angle of the monitor was decided upon by each subject. As

De Wall *et al.* (1992) pointed out, this raised monitor places the cervical spine in its natural anterior curvature and enables a natural upright posture to be maintained, and should thus decrease any musculoskeletal discomfort in the neck and upper back by reducing the muscular load. Following the recommended positioning put forward by Hedge *et al.* (1999), the height of the keyboard was adjusted in order to place the wrists in a more neutral position by establishing a relaxed flexion at the elbow and more importantly reducing hyperextension of the wrist. Because of the fixed height of the desk, the relative height of the keyboard was adjusted by adjusting chair height and introducing a footrest where necessary.

The mouse was adjusted to the same height as that of the keyboard and its horizontal position was such that it was as close to the distal point of the operator's shoulder as possible. Several studies (Fernström and Ericson, 1997; Cook *et al.*, 2000) have shown that a mouse closer to the midline of the body results in reduced muscular tension and discomfort in the trapezius and deltoid. A mouse located further from the midline not only increases shoulder abduction, but also results in greater ulnar deviation in the wrist.

For Condition 3, the final workstation was set up with individualised physical dimensions similar to those of the Personalised workstation, with the addition of a specifically designed mobile wrist support (Figure 11). Because the wrist support raised the forearms off the table, it was necessary to increase the chair height to prevent shoulder elevation or an angle of less than 90° at the elbows. As a result of the raised chair, there was a need for a footrest in some cases, and the monitor was also raised further in order to maintain the alignment of the centre of the screen with eye-level. Aarås *et al.* (1998) and Lintula *et al.* (2001) suggested that such a wrist support would decrease musculoskeletal discomfort and strain in the neck and shoulder regions as a result of reduced muscular demand. The aim of the support was also to promote more neutral wrist postures by reducing wrist extension, and minimising radial and ulnar deviation while moving the fingers and hands to and from the keyboard, the number pad and the mouse.
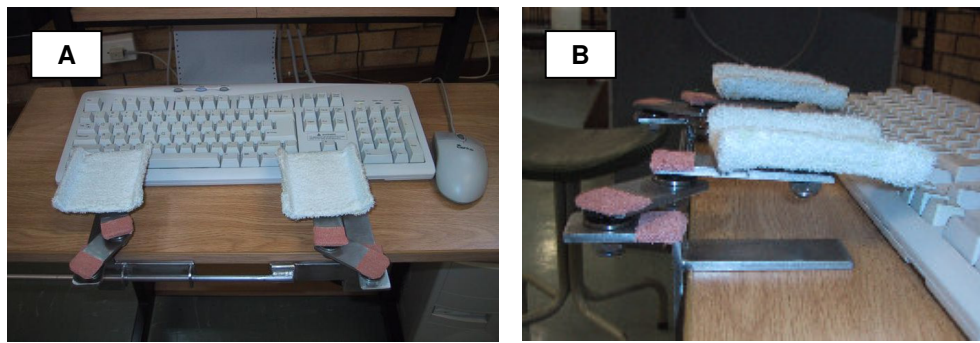
Figure 11: Frontal view (A), and side view (B) of the mobile wrist support.

The dimensions of the three workstations are presented in Table III. When assessing the workstations non-parametric statistics revealed significant differences. Although desk height remained unchanged throughout, changes in chair height altered the relative height of the desk. There was a significant increase in chair height from 483mm in the Standard workstation to a mean of 570mm (±9.98 SD) in the Personalised and 583mm (±10.80 SD) in the Wrist Support workstation. Although there was no difference between the chair height in the Personalised and Wrist Support workstations, the increase in chair height from the Condition 1 to Condition 2 and 3 were mirrored by changes in the height of the footrest. No footrest was used in the Standard workstation; however, in order to ensure that the keyboard was at the correct height in the Personalised and Wrist Support workstations, the chair had to be raised as it was not possible to lower the table. In some cases this resulted in the feet of the shorter subjects' being insufficiently supported. A footrest was therefore implemented. The mean footrest height in the Personalised workstation was 51mm (±52.50 SD) which was not significantly different to the 62mm (±47.84 SD) footrest used in the Wrist Support workstation. Similarly the height of the centre of the computer monitor, which was 180mm in Condition 1, increased significantly to 419mm (±50.43 SD) in the Condition 2 and 451mm (±41.53 SD) in Condition 3. This ensured that the centre of the screen was positioned at eye level so that a neutral neck posture could be assumed while focusing the eyes on the monitor. Although the monitor was slightly higher in Condition 3, this was not significantly greater than in Condition 2 (see Figure 12). These data demonstrate that the "ideal" workstation is significantly different to the Average Standard computer

workstation which is generally utilised by operators of varied anthropometric characteristics.
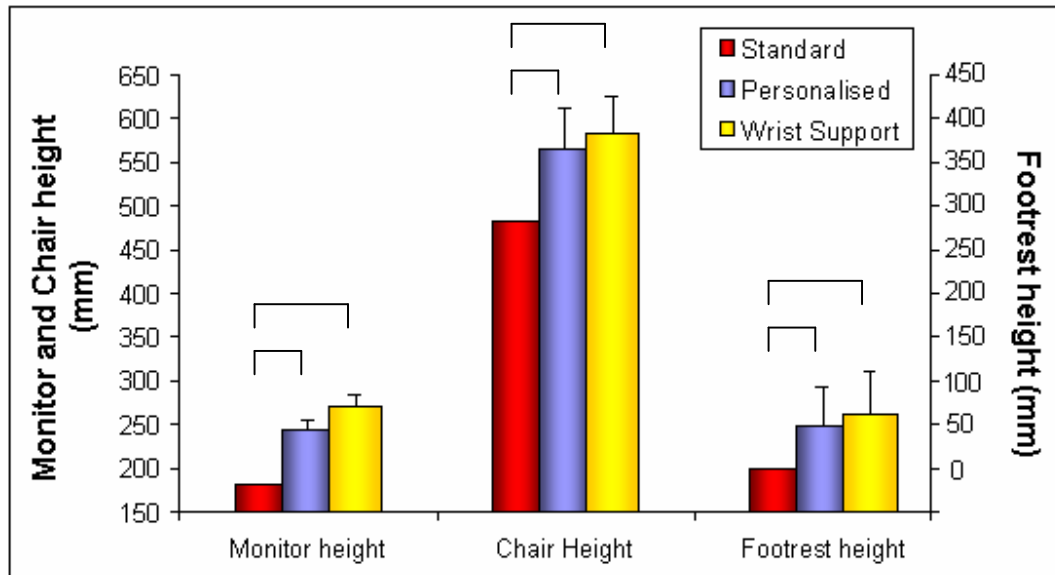
Figure 12: Workstation dimensions.
(Bars denote significant difference between workstations, p<0.05)

Neither the keyboard nor the mouse were raised in Condition 1 or 2. The keyboard was however raised by a mean of 11mm (±10.16 SD) when using the mobile wrist support and the mouse was raised by a mean of 23mm (±9.10 SD). Because the wrist rest raised the arms above the desk slightly, these small, insignificant adjustments made to the actual keyboard and mouse height prevented the wrists from being forced into flexion. The mean width of the wrist rest was 358mm (±19.69 SD). A schematic diagram demonstrating the positions from which the workstation measurements were taken is presented in Figure 13.

Figure 13: Schematic diagram of the workstation components.

    A) Chair height
    B) Keyboard and mouse height
    C) Footrest height
    D) Desk height
    E) Monitor height

In terms of workstation layout, there was no significant difference between the chair height for the Short, Medium and Tall subjects in both the Personalised and Wrist Support workstations. There was however a significant difference between th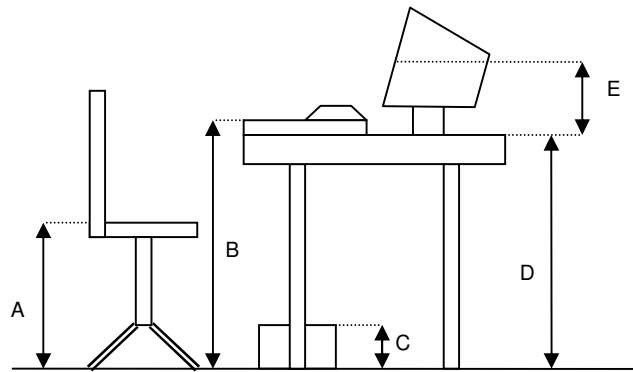e height of the footrest used by all three subject groups in both Condition 2 and 3 ($p < 0.05$). Therefore, although all subjects were raised by increasing the height of the chair so that the relative height of the keyboard allowed natural upper limb postures, the lower extremity length of shorter subjects was accounted for with the implementation of a footrest. There was also a significant difference between monitor height for the three subject groups in both the Personalised and Wrist Support workstations, with it being substantially higher for tall subjects.

In the Wrist Support workstation the height of the keyboard and mouse was not significantly different for the three subject groups. There was a limited degree to which each of these could be raised since it was necessary for the wrist support to have sufficient clearance above the keyboard and mouse. The only difference in the width of the wrist rest was between the short (346mm ± 12.71SD) and tall (370mm ± 19.72SD) subject groups. Although shoulder breadth was used as the basis for this dimension, it was adjusted subjectively by the participants for their personal preference during the familiarisation period.

Table III: Dimensions of the three workstations assessed in this study.

(means and standard deviations in brackets; S = Short, M = Medium, T = Tall)

	Std.	Personalised				Wrist Support			
		S	M	T	Avg	S	M	T	Avg
Desk height (mm)	763 (0.00)	763 (0.00)	763 (0.00)	763 (0.00)	763 (0.00)	763 (0.00)	763 (0.00)	763 (0.00)	763 (0.00)
Chair height (mm)	483 ** (0.00)	565 (10.19)	563 (11.02)	570 (13.63)	570 * (9.98)	583 (11.01)	581 (13.74)	587 (11.02)	583 * (10.80)
Centre of screen (mm)	180 ** (0.00)	374 (36.61)	412 (21.47)	471 (32.11)	419 * (50.43)	417 (18.89)	439 (14.03)	498 (32.82)	451 * (41.53)
Keyboard raised by (mm)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	9 (8.86)	6 (8.01)	16 (11.78)	11 (10.16)
Mouse raised by (mm)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	20 (0.00)	22 (5.29)	26 (15.13)	23 (9.10)
Footrest height (mm)	0 ** (0.00)	112 (37.01)	41 (19.44)	0 (0.00)	51 * (52.50)	112 (23.07)	66 (17.41)	0 (0.00)	62 * (47.84)
Wrist Support width (mm)	-	-	-	-	-	346 (12.66)	357 (20.10)	370 (19.67)	358 (19.69)

* denotes significant difference (p<0.05) between the Standard and Personalised workstation
* denotes significant difference (p<0.05) between the Standard and Wrist Support workstation

Subject characteristics

In order to assess the effect each of the three workstations had on users of varied anthropometric characteristics, subjects of varied stature participated in this study. Figure 14 demonstrates the vast difference in the morphology of the subjects who were expected to operate computers with the same workstation layout. The sample consisted of 30 participants (10 female, 20 male) all of whom were students at Rhodes University. The ages of subjects ranged from 20 to 29 years with the mean age being 23 years. Eleven of the subjects wore glasses while working at the computer, one of which wore bifocals. Only two of the subjects were left hand dominant. Subjects were required to have a good level of computer experience and competent typing skills, and in order to

participate in the study they could have no history of computer-related musculoskeletal disorders. On average the subjects had 8.2 years (±3.19 SD) of computer experience and they spent on average 7 hours (±2.41 SD) a day at the computer. The maximum time spent working at a computer in one day was reported to be 24 hours with up to 8 hours of uninterrupted work in a single sitting.

Figure 14: The shortest (1476mm) and tallest (1964mm) subjects required to work at the same computer workstation.

The sample was subdivided into three groups according to stature in order to determine whether the subjects' responses to the three workstations were influenced by anthropometric characteristics. Subjects in the "Short" group (n=8) had a stature of less than 1650mm, those in the "Medium" group (n=15) were between 1650mm and 1800mm and "Tall" subjects (n=7) were taller than 1800mm. In order to maximise the difference between the groups, data for the tallest subject in the "Short" group and the four shortest and tallest subjects in the "Medium" group were discarded so the sample size for each of the three groups was seven for comparisons to be made between the three groups. Figure 15 illustrates the significant difference between the mean statures of the three subject groups ($p < 0.05$). However, when investigating the responses of the subjects

during the experimental procedure of evaluating the possible benefits of the personalised stations, with and without the mobile wrist support, all 30 subjects were assessed in all three conditions.
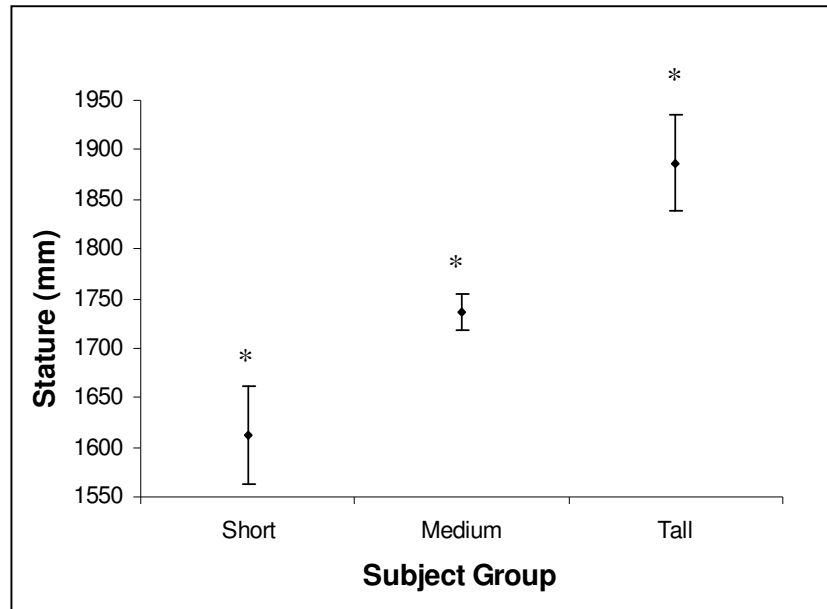
Figure 15: Stature of the Short, Medium and Tall subject groups.
(* denotes significant difference between subject groups, p < 0.05)

The anthropometric data presented in Table IV were used to personalise a workstation for each participant. The significant difference in basic anthropometric measurements was evident in terms of lower limb length, popliteal height, upper limb length, forearm length as well as seated eye height. These findings support the indication by Pheasant (1996) that a positive correlation occurs between stature and length of the different body segments. Although there was no difference in shoulder breadth between the medium and tall groups, the shoulder breadth of short subjects was significantly less than that of the other two groups. This is probably due to the fact that all of the short subjects were female while the medium and tall subject groups consisted only of males and males do tend to have a greater shoulder breadth than females.

Although mass increased with increasing stature, there was no significant difference between the short and the medium groups or between the medium and the tall groups. The tall group, however, had a significantly greater mass than the short group. When assessing body mass relative to stature and analysing Body Mass Index (BMI) there was no difference between any of the three subject groups. Although Coleman *et al.* (1998) indicated a link between the discomfort associated with seated working postures and BMI, any difference between the discomfort experienced by the subjects in this study was independent of their BMI.

Table IV: Anthropometric data of each subject group.

(means and standard deviations in brackets)

	SHORT GROUP	MEDIUM GROUP	TALL GROUP
Sample size (n)	7	7	7
Stature (mm)	1612.4 * (49.86)	1736.1 * (17.93)	1886.3 * (48.48)
Lower limb length (mm)	825.9 * (48.73)	907.9 * (54.00)	977.4 * (40.09)
Popliteal height (mm)	381.6 * (22.72)	417.6 * (18.01)	447.7 * (9.88)
Upper limb length (mm)	706.9 * (57.68)	766.9 * (33.50)	829.7 * (27.33)
Forearm (mm)	434.7 * (18.30)	484.0 * (17.06)	522.1 * (13.95)
Sitting eye height (mm)	752.0 * (23.46)	799.4 * (16.26)	869.1 * (37.76)
Shoulder breadth (mm)	398.3 * (17.55)	440.3 (33.15)	455.9 * (33.57)
Mass (kg)	67.4 * (9.29)	78.3 (9.54)	81.5 * (9.66)
BMI	25.9 (3.73)	25.9 (3.25)	22.9 (2.50)

* denotes significant difference (p<0.05) between subject groups

MEASUREMENT AND EQUIPMENT PROTOCOL

Demographic and anthropometric measures

Before testing basic demographic data were obtained for each subject. This included age, years of computer experience, average daily hours spent working at a computer and general type of work tasks carried out at the computer. Relative anthropometric measures were also recorded, as they were used in the setting up and assessment of the "ideal" computer workstation. The general data collection sheets for demographic and anthropometric data are shown in Appendix B.

Stature

Stature was measured in order to assist with the positioning of the various components of the workstation as well as to assign subjects to one of three categories: Short (below 1650mm), Medium (between 1650mm and 1800mm) or Tall (above 1800mm). This enabled the assessment of the effect of the three computer workstations on operators of different anthropometric dimensions. Subjects were required to stand upright and barefoot with the calcaneus, buttocks, shoulders and head placed against a wall and with the head erect and eyes looking directly ahead. A tape measure was used to measure stature from the vertex in the mid-sagittal plane to the floor.

Lower extremity length and popliteal height

A Takei anthropometry set was used to obtain these two measurements which were fundamental in determining chair and footrest height. Leg length was measured from the greater trochanter to the floor. To standardise the measurement it was taken on the right hand side, and the subjects were required to be barefoot. The greater trochanter was located by palpating the lateral hip area while the subject abducted the leg moderately, and internally and externally rotated the hip.

Pheasant (1996) advised that the height of the seat pan should be slightly below popliteal height in order to ensure that the user's thighs are approximately horizontal, with the lower leg vertical and the feet resting flat on the floor. Popliteal height was

measured when the subject was barefoot and seated with the feet rested firmly on the ground. The measurement was taken from the floor to the popliteal angle at the underside of the knee where the tendon of the biceps femoris muscle inserts into the lower leg.

Sitting eye height

Since the centre of the computer screen was positioned at eye level, sitting eye height was an important measurement as it determines the vertical distance between the sitting surface and the inner corner of the eye (Pheasant, 1996). Subjects were required to sit on a box positioned against a wall. With the buttocks, shoulders and head in contact with the wall, and eyes looking directly ahead, eye level was marked off on the wall and the distance between the mark and the sitting surface was recorded.

Upper limb length, forearm length and shoulder breadth

As the optimal position of the keyboard and mouse, in terms of the distance from the edge of the table, is dependent on upper limb length, it was deemed necessary to record arm length. In order to obtain this value the vertical distance from the floor to the acromion was measured. Fingertip height was then obtained by measuring the vertical distance from the floor to the dactylion and this was subtracted from standing shoulder height to calculate upper limb length. This was done on the right hand side so as to standardise the measurement.

The measurement of forearm length (elbow-fingertip length) required that the forearm be flexed to 90° with the upper arm vertically placed against a firm surface and the hand and fingers extended to the anatomically neutral position. The distance from the firm surface to the tip of the middle finger was determined. Forearm length was important for the positioning of the keyboard and mouse in the personalised workstation.

Gilad and Harrel (2000) reported that the horizontal position of the mouse was affected by the width of the operator's shoulders, reasoning that individuals with slightly broader shoulders are less likely to experience discomfort or muscular strain as a result of the

lateral position of the mouse thus allowing for a more distal mouse position while maintaining acceptable anatomical shoulder postures. The horizontal distance across the shoulders, measured between the acromia, was therefore recorded. This value was also used as a basis to determine the position of the wrist rest for Condition 3.

Body mass

Body mass was recorded in order to calculate Body Mass Index (BMI). Coleman *et al.* (1998) have suggested that physical discomfort brought about by prolonged seated working postures may be related to BMI as a result of the "preferred" height of a chair's lumbar support being associated with the user's BMI. A *Seca* digital scale was used to measure body mass and BMI was then calculated using the following equation:

$$BMI \quad = \quad \frac{Mass \quad (kg)}{Stature^2 \quad (m^2)}$$

Workstation dimensions

Condition 1

Condition 1 (Figure 16a) was set up according to the dimension presented in Table II and was the same for all subjects regardless of stature. In terms of the mouse placement, its vertical position was the same as that of the keyboard. The subjects had free choice as to the horizontal position of both the keyboard and mouse.

Condition 2

After anthropometric measurements of each subject were made, the workstation for Condition 2 was assembled (Figure 16b). Firstly the chair was adjusted to place the operator in the most natural seated posture. The height of the seat pan was raised or lowered within its adaptable limits so that the sitting posture was optimal and the keyboard was at a suitable vertical level. With the shorter subjects a footrest was used when necessary to ensure that the feet were firmly supported and that the legs were in a natural position with approximately 90° angles at the knees and hips in order to minimise

discomfort and the risk of developing musculoskeletal problems associated with increased pressure on the posterior aspect of the thighs due to chair height. Therefore the distance from the seat pan to the resting surface of the feet was marginally less than the popliteal height for each subject.

The dimension obtained for each subject's sitting eye height was measured from the seat pan and the centre of the screen was aligned to this level. In order to reduce wrist extension during typing, the height of the keyboard was adjusted depending on the height of the working surface and the height of the chair. Low cost interventions, such as books and wooden boxes, were used to implement these alterations. The mouse pad was then positioned at the same height and directly adjacent to the keyboard in order to keep the mouse as close to the operator's midline as possible.
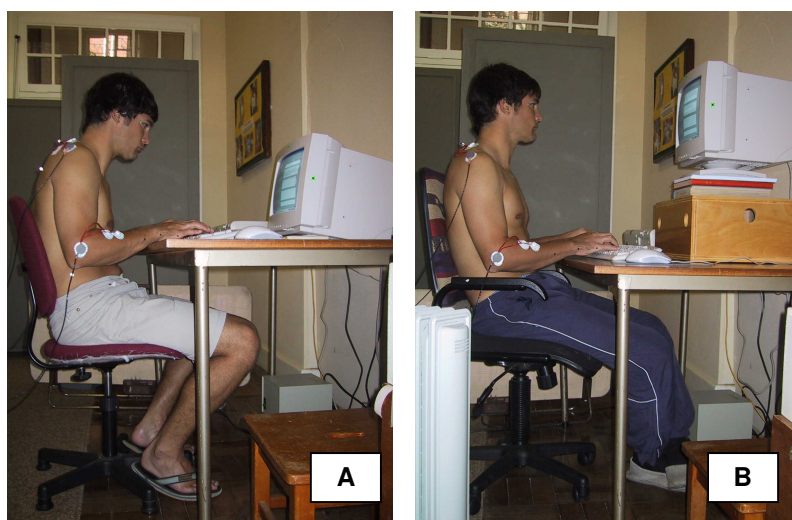
Figure 16: Physical design of the (A) Average Standard workstation, and (B) Personalised workstation.

Condition 3

The dimensions used in the Personalised workstation were adjusted marginally for Condition 3 in order to accommodate the wrist support, which was attached to the working surface. The aim of the wrist support was to further optimise the working conditions for subjects by offering support for the forearms and reducing the likelihood of

wrist extension and radial and ulnar deviation. Because the wrist support raised the forearms marginally above the keyboard, it was necessary to raise the other components of the workstation in order to allow a natural posture to be maintained.

Biophysical measures

Video analysis

A *Sony* digital video camera was set up in three different positions in order to assess the effect of the different workstations on various joint angles. Ten seconds of video footage was obtained during each sub-task of the performance test. This footage was sufficient to assess the mean and the range of joint angles using the *SiliconCoach* software package.

Position 1

The camera was placed 1975mm to the right of the subject, at a vertical height of 763mm. From this position it was possible to assess various joint angles pertaining to the subject's general seated posture. For these measurements to be made, reflective markers were positioned at a point marking the centre of the monitor, on the outer canthus of the eye, the seventh cervical vertebra (C7), the fourth thoracic vertebra (T4) and on the iliac crest. Males wore no clothing on the upper body and females wore a sleeveless, tight top which did not interfere with the placement of markers. In terms of the iliac crest the female's shirts were taped up to the side so that the marker on the skin was exposed.

In order to determine the effect of monitor height on head position and the degree of neck flexion, gaze angle, head angle and neck angle were measured. In terms of general seated posture, trunk angle and thoracic bend were measured.

Similar to a study by Sommerich *et al.* (2001) gaze angle was taken as the angle between the horizontal to a line joining the external canthus (juncture of eyelids) and the centre of the monitor (see Figure 17a).

Villanueva *et al.* (1997) defined Reid's line as the line connecting the external canthus and the tragion of the ear. The angle between Reid's line and the horizontal was measured and termed head angle (Figure 17b). A positive angle occurred when Reid's line lay superiorly to the horizontal such as when the head is tilted backwards. However, some studies have used the Frankfurt plane, which lies approximately 10° below Reid's line and can be defined as the horizontal plane at the level of the upper edge of the opening of the external auditory meatus and the lower border of the orbital margin. Reid's line was used in the present study because, as Villanueva *et al.* (1997) pointed out, it is easier to measure accurately from video analysis than the Frankfurt plane.

Based on the findings by Sommerich *et al.* (2001) neck angle was measured between the vertical and a line joining C7 and the tragion (Figure 17c).

Trunk angle gave an indication of the general seated posture and use of the backrest. This angle lies between the vertical and a line joining the iliac crest and T4 (Figure 17d). This measurement was based on recommendations by Bhatnager *et al.* (1985). Thoracic bend also gave an indication of general posture and it was defined as the angle formed by C7, T4 and the iliac crest (Figure 17e). C7 and T4 were marked with protruding markers and are illustrated in Figure 21 (p 71).
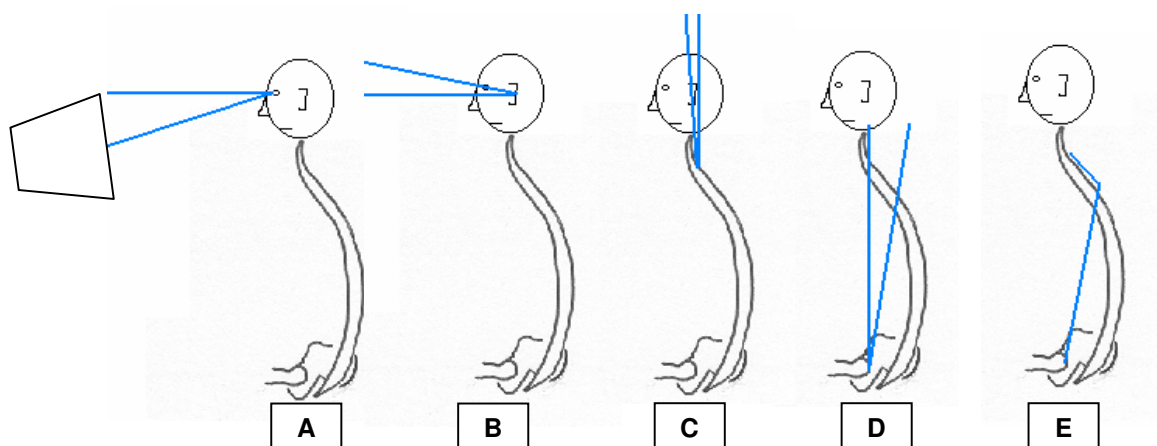

Figure 17: Joint angles measured with the use of video analysis.

A) Gaze angle   D) Trunk angle
B) Head angle   E) Thoracic bend
C) Neck angle

Position 2

The camera was placed 745mm to the right of the subject, in the same horizontal plane as the keyboard. This camera angle enabled wrist flexion and extension to be measured. The angle between three markers drawn on the skin with a permanent marker was used to determine the posture of the wrist. The distal marker was positioned on the small metacarpophalangeal joint, the middle marker on the triquetrum, and the proximal marker on the ulnar, 60mm proximal to the second marker and in the same horizontal plane (see Figure 18). A neutral wrist posture would enable a line to pass straight through all three markers. This reference position has an angle of 0°. Any wrist extension resulted in a negative angle, while a positive angle was reflective of flexion.
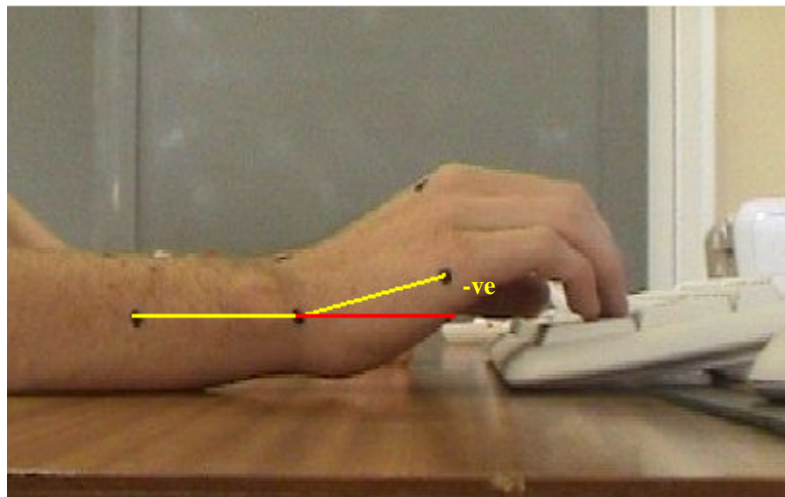
Figure 18: Surface markers and angle used for the analysis of wrist posture.

Position 3

The camera was positioned 1270mm directly above the subject in order to assess ulnar and radial deviation while operating the keyboard and mouse. The angle between three markers on both hands was used to assess ulnar and radial deviation. The first of three markers were positioned slightly proximal to the middle metacarpophalangeal joint, the second on the mid-point of the wrist joint, and the third on the mid-point of the forearm 60mm proximal to the wrist joint (see Figure 19). In a neutral position the reference

position would be 0°. A negative angle indicated ulnar deviation, and a positive angle was the result of radial deviation.
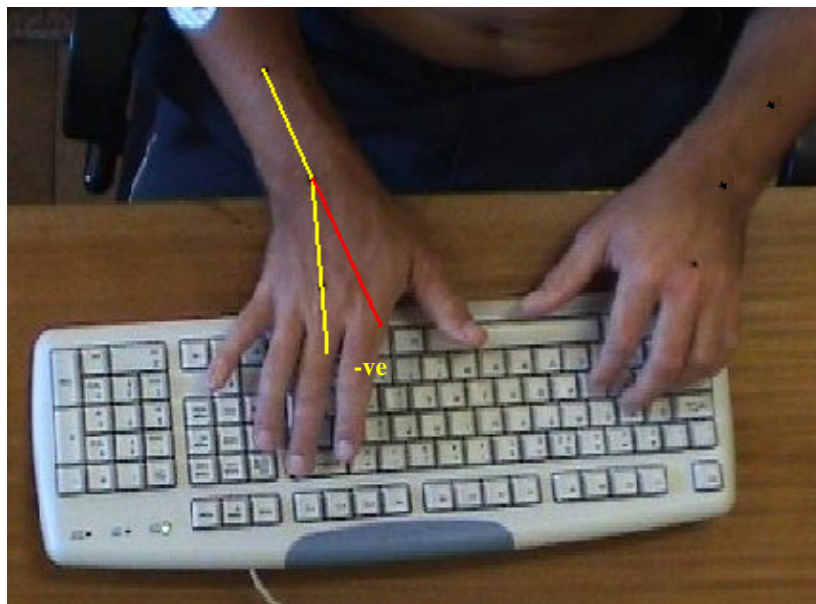
Figure 19: Surface markers and angle used for assessment of radial and ulnar deviation.

Photographic analysis

A digital camera was used to photograph a posterior view of the subject in order to assess any differences in shoulder elevation or depression. One photograph was taken during each of the sections of the performance test. The ground electrodes for the trapezius EMG, which were located on the acromia, and the C7 marker were used as the reference points for this joint analysis (see Figure 20). *Meazure* software was used to obtain the angles.
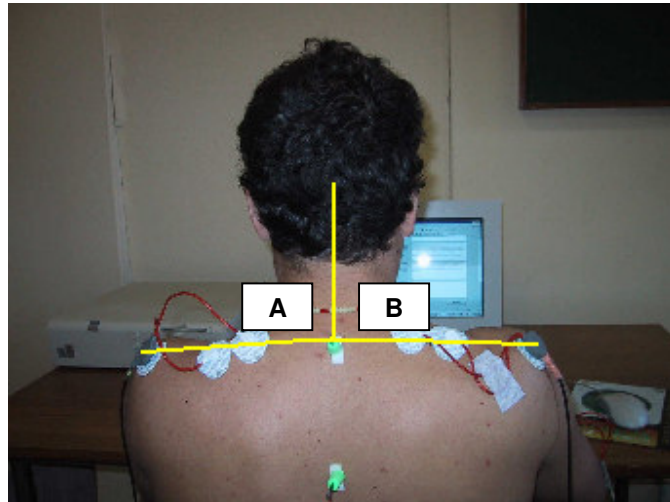
Figure 20: Photograph used to assess shoulder symmetry.

Differences between angles A and B were compared.

Physiological measures

EMG analysis

Since the risk of developing work-related musculoskeletal disorders is elevated when high levels of muscle activity are sustained for prolonged periods (Straker and Mekhora, 2000) muscle activity was deemed a necessary measure to consider. A surface electromyography (EMG) device, such as the Muscle Tester (Mega ME3000P4, Mega Electronics Ltd, Finland), offers a comprehensive tool for the assessment of muscle activity. EMG measurement is accessed by attaching electrodes to the surface of the skin and recording the changes in electrical activity in the muscle directly beneath them.

The Muscle Tester consists of a ME3000P4 Measurement Unit, a 4MB memory card, and two EMG preamplifier cables each of which have two measurement channels which attach to the electrodes. This EMG device is run on a MegaWin software programme. The sampling rate was set to 1000Hz, and one minute of data were collected and stored during each of the five tasks within the performance test.

Accurate EMG recording requires that the disposable, pre-filled Silver-Silver Chloride (Ag/AgCl) electrodes be properly positioned according to the muscles to be assessed.

The two active electrodes were positioned no more than 50mm apart and equidistant from the midpoint of the muscle, with a reference electrode, which is used to "ground" the muscle from irrelevant electrical contamination, positioned on a separate muscle approximately 100mm from the measuring electrodes. When preparing the subject, prior to electrode placement, a measuring tape was used to obtain the midpoint of the muscle which was then marked. The area where the electrodes were to be placed was then shaved and cleaned with an alcohol swab in order to ensure a good contact and to reduce interference. Electrode positions were measured relative to the participant's bony landmarks on the first test day and replicated on subsequent testing days.

Based on previous findings by Sommerich *et al.* (2001) and Kim *et al.* (2003b) the electrical activity in the upper trapezius was selected for assessment in the present project. In order to measure the responses of the upper trapezius active electrodes were centred at a point 10mm lateral to the midpoint of a line between the seventh cervical vertebra (C7), and the acromion and the reference electrodes were placed on the acromia (Figure 21).

**Figure 21: Trapezius electrode placement and identification
of cervical and thoracic markers.**

Because a deliberately diverse sample was used, and in order to facilitate interindividual comparison, the muscle activity was relativised as a percentage of the maximum

voluntary contraction (MVC). MVC of the upper trapezius was obtained by offering manual resistance to the shoulders during attempted shoulder elevation. As recommended by Aarås *et al.* (1997) this maximal contraction was held for no longer than 2s in order to avoid the onset of fatigue, and each subject had two attempts at maximum contraction.

In order to assess the muscular activity resulting from the differing keyboard positions and wrist support, the EMG of the wrist extensors was measured. Following the protocol in a study conducted by Mogk and Keir (2003), one of the active electrodes was positioned one third of the distance from the proximal end of a line from the medial epicondyle to the distal head of the radius with the forearm supinated, and it was placed over the palpated body of the muscle. The second active electrode was located 20mm distal to that. The muscles being considered were the extensor carpi radialis, extensor carpi ulnaris and extensor digitorum communis. As suggested by Forsman *et al.* (2002) the reference electrode was positioned on the olecranon (see Figure 22). Manual resistance was implemented over the entire hand and fingers, and in order to obtain a value for MVC of the wrist extensors the subject attempted to extend the wrist and fingers maximally for 2s. The raw data of an EMG response and a data sheet displaying the values is presented in Appendix B.
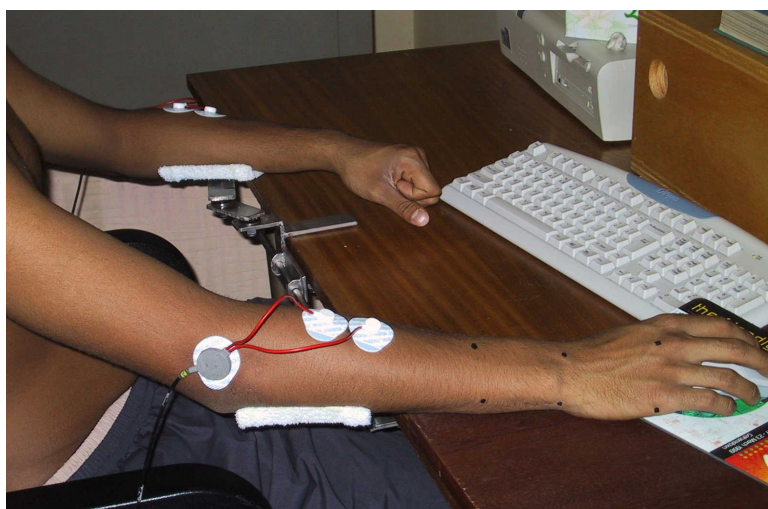

Figure 22: Forearm extensor electrode placement.

Perceptual responses

Although the physiological responses give an indication of how the subjects' bodies responded to the various conditions, it is important to ascertain how the subjects perceived the postural demands placed on them at each of the workstations. Perceptual responses acknowledge the importance of the human factor and allow for a tangible assessment of what the individual is experiencing. The following perceptual responses were obtained through the use of questionnaires completed at the end of the performance task.

Body discomfort

Identifying areas of discomfort is of great importance when considering an individual's perceptions of various workstations (Evans and Patterson, 2000). A computer workstation specific Body Map (Figure 23), subdividing the body into 15 segments, was used so that subjects could specify the exact location of their perceived discomfort in terms of the body as a whole. While these responses identify specific areas, they are not quantifiable, therefore a numeric intensity scale ranging from 0 (No discomfort) to 5 (Extreme discomfort) was used in association with the Body Map to enable the body regions and intensity of discomfort to be assessed thus giving a quantifiable measure. On completion of the performance test, subjects were asked to rate the discomfort of each of the 15 body segments on the intensity scale. Thereafter they were required to identify and rate the three areas they perceived to be of the worst discomfort (see Appendix B).
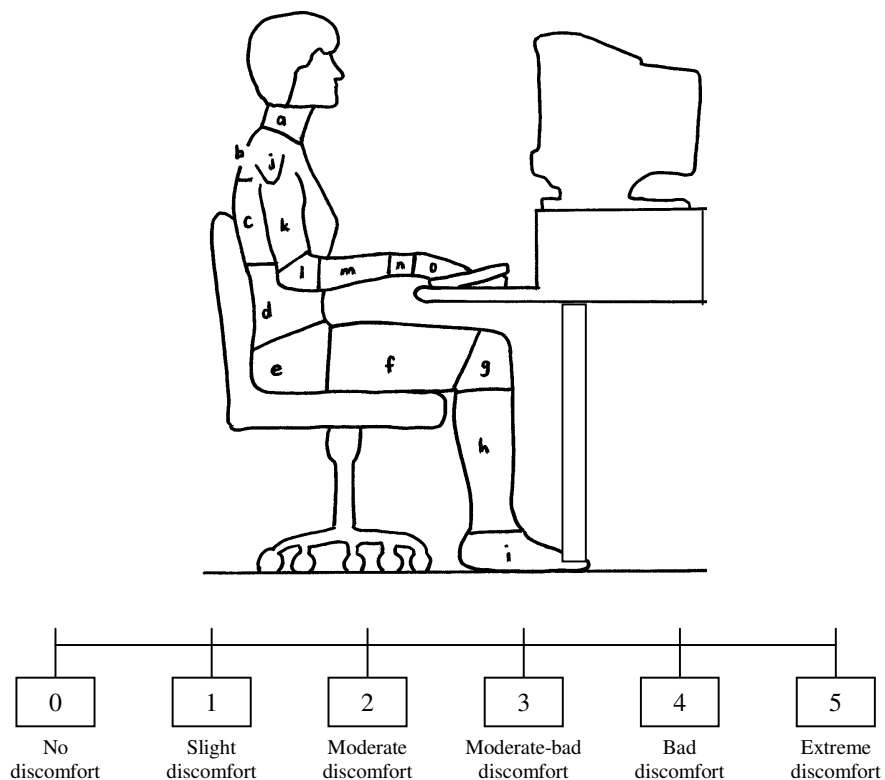
Figure 23: Body Map and discomfort rating scale.
(Adapted from Ergotrack, 2003)

Visual discomfort

When adjusting the height of the monitor several authors pointed out the need to consider the effect this would have on the visual system as well as the musculoskeletal system (Bauer and Wittig, 1998; Burgess-Limerick *et al.*, 2000; Kim *et al.*, 2003b). Each individual's perception of visual discomfort was therefore assessed. Participants were required to complete a visual discomfort appraisal (see Appendix B) based on the following symptoms, which were similar to those used in a survey by Sommerich *et al.* (2001): blurred vision, and burning, itching, tired, aching, dry and watering eyes.

Perceptions of the workstation

An individual's perceptions of a workstation may be influenced by the design dimension of the workstation they use on a daily basis, and although humans do have the ability to adjust to a new workstation it is important to be aware of their perceptions of its dimensions. Subjects therefore completed a questionnaire which addressed how they perceived the layout of the workstations being tested (see Appendix B). The dimensions the subjects were required to report on included chair height, screen height, screen position in terms of horizontal distance from the user, screen tilt (see Figure 24), keyboard height, mouse height and the mouse's horizontal position.
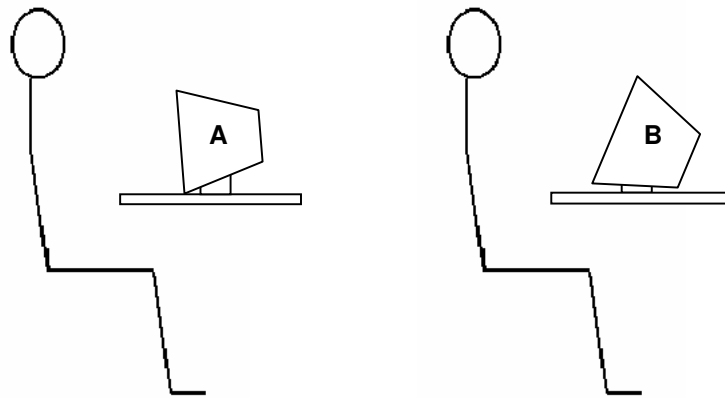
Figure 24: Screen tilted (A) towards the user, and (B) away from the user.

Preference

In the final questionnaire, completed after the third testing session, subjects were required to rank the three workstations in order of preference, identifying the reason(s) for their choice (Appendix B).

Performance efficiency

There are several diverse tasks including data entry (textual and numerical), text editing, and web browsing which can be carried out by computer users. These tasks place different physical and cognitive demands on the operator and require the use of various

input devices. A performance efficiency test incorporating all of these tasks was therefore created in order to assess the several facets of computer jobs.

A battery of performance tasks with five separate sections was created in Microsoft Access (see Appendix B). For each section of the test subjects were instructed to work through the task as quickly and accurately as possible, as performance efficiency was determined by assessing speed and accuracy of each section within the test as well as the complete work requirement. This was done by timing how long the subjects took to complete each section and totalling the number of errors made with the use of a "file-compare" protocol, which compared the data entered by subjects to the original data. Although subjects were aware that they were being timed, they were permitted to correct any errors with the knowledge that this would increase their time to completion while improving their accuracy.

The first two sections required use of the keyboard only. In the first section there were 10 text entry fields next to which there was a paragraph of text. Subjects were instructed to type this exact paragraph into the text boxes provided. In the second section six blocks of numerical data were entered into the relevant fields rather than textual data as in section one. The third section of the performance test required use of the mouse only. This section consisted of 50 "combo boxes" from which subjects were instructed to select the correct or appropriate answer to various questions. The fourth part of the test was a data editing task which required use of both the keyboard and mouse. In this section 15 correct references were displayed, and directly below each one was the same reference containing three deliberate errors which subjects were instructed to edit so that it was identical to the correct reference. The final section involved a second textual task similar to that completed in the first section (see Appendix B).

After completion of each section the subjects clicked the "Next" button to save that section and open the form for the following section. After the final section the "Finish" button was clicked in order to save and close the form. The data entered by the subjects

was automatically stored in the database on completion of the test and this was later used to analyse the effect of the three test conditions on performance efficiency.

FAMILIARISATION

In order for subjects to become familiar with the general environment as well as the workstation, they were required to work at the workstation for 30 minutes immediately prior to testing. This familiarisation period was enforced for each testing session in order to standardise the experimental protocol and also to ensure that differences in responses caused by variation in the period prior to testing were minimised if not eliminated.

EXPERIMENTAL PROCEDURE

Subjects reported to the laboratory on three separate occasions. During the first session subjects were given a verbal explanation of experimental procedures followed by a letter of information (Appendix A) which they were required to read before signing the informed consent (Appendix A) after which subject demographic and anthropometric data were recorded.

Each subject was tested at the standard workstation first as this was deemed to be familiar and similar for all subjects, and formed the basis for comparisons with the other two workstations. During the second and third testing sessions subjects were randomly tested in the personalised and wrist support workstations, and testing was scheduled for the same time of day for the same subjects in order to minimise the influence of diurnal differences. The following testing protocol was identical for all three sessions.

After the familiarisation period, markers were placed on the subject for video analysis. Markers were measured relative to the participant's anatomical landmarks on the first day and replicated on subsequent days. The placement of EMG electrodes were then determined and the skin was shaved and cleaned with alcohol swabs. EMG electrodes

were placed on the relevant muscles and the cables attached to the electrodes. After settings on the measurement unit were adjusted MVC values were obtained. The subject was then required to be seated at the workstation while the performance testing programme was explained and demonstrated, after which the subject began the performance test and a timer was started to determine their time to completion.

Joint angle and muscle activity data were collected during the first minute of each of the five sections of the performance test. At the end of the overall test, the time to completion was recorded, and subjects were asked to complete a questionnaire regarding body and visual discomfort, and their perceptions of the physical dimensions of the workstation. After the final testing session subjects were required to rank the three workstations according to their personal preference. The number of errors made during the test were then totalled and recorded. Joint angles, muscle activity, perceptual and performance efficiency results from the three workstations were then analysed.

STATISTICAL ANALYSIS

All experimental data were downloaded to a STATISTICA (Version 6.0) statistical package and basic descriptive statistics relative to the variables assessed were gathered thus providing general information concerning the sample (see Appendix C). The level of significance was set at $p < 0.05$ throughout the statistical treatment of the results, providing a level of confidence of 95%. Hence, there were still five chances in a hundred that a Type I error (rejecting a true hypothesis) could have been committed.

All data were tested for normality using the Shapiro-Wilks normality test ($p > 0.05$) before any statistical analyses were performed on the data. The data which were not normally distributed were transformed using the $\log(x)$ function and retested for normality. Levene's test was also performed on the data to test for homogeneity of variance ($p > 0.05$) to ensure that parametric statistics were rightfully used. Parametric statistics was used on all normally distributed data with homogeneity of variance, otherwise the non-parametric equivalent was used.

One-way ANOVAs were used to analyse the independent variables (subject groups and computer workstations). These statistical tests were used to determine whether there was a significant difference between the anthropometric variables of the three subject groups, and between the physical dimensions of the three workstations.

When analysing the dependent variable, one-way ANOVAs were used to investigate differences between the three subject groups (n=7 for each group) within each of the workstations. Generally differences were only found to occur in the Average Standard workstation because it accommodated only those subjects of "average" morphology while the two personalised workstations ensured an "optimal" layout for all subjects thereby eliminating the differences in responses of the different subject groups.

One-way ANOVAs were also used to analyse the difference in responses at the three workstations. For these analyses the data from the subject groups were pooled and the statistical tests were performed on a sample of 30. Following all ANOVAs that demonstrated a significant difference ($p < 0.05$) the Scheffe's post hoc test was used to determine where the differences existed.

CHAPTER IV
RESULTS AND DISCUSSION

INTRODUCTION

A large and growing portion of the working population are becoming dependent on computers for everyday use. This workforce is anthropometrically diverse, yet individuals are often expected to work at computer workstations with 'average' physical dimensions and a limited degree of adjustability. The basic principle of adjusting the workplace to accommodate the worker is an ideal which is often overlooked when "standard" equipment or furniture is used (Smellie, 2003). In a general or 'public' office environment furniture is usually purchased in bulk and without consideration of the end-users who may have extremely varied morphological characteristics. Due to the perceived costs associated with personalising each employee's computer workstation, computer operators are generally expected to adjust their natural body alignment and posture to "fit" the workplace. These "standard" workstations are designed to accommodate users with average morphological dimensions, and as a result it is the shorter and taller computer operators who are the worst affected by the workstation. There are, however, several "low-cost, no-cost" interventions which can easily be implemented in order to improve the workplace to accommodate computer operators of varying sizes.

In the choice of subjects for this project every attempt was made to include a large range of statures from short, through medium height to tall subjects. In order to identify the differences of the responses of these subjects in the Standard workstation, the data are tabulated separately for the three groups based on stature. However, data for all subjects were then pooled for analysis of responses in the Personalised and Wrist Support workstations since personalising the workstations allowed for "optimal" working postures for all subjects. A personalised workstation should allow more natural bodily alignment, which in turn decreases the muscular effort required to maintain the working posture, thereby reducing any physical discomfort experienced by the computer operator

and minimising the distraction of concentration which may be caused by this discomfort, with the ultimate result being seen in the enhancement of performance efficiency. The benefits associated with the personalisation of standard computer workstations can be measured in terms of the operators' biophysical, physiological, perceptual and performance responses.

BIOPHYSICAL RESPONSES

When humans adopt awkward working postures they are likely to be exposed to a substantial amount of unnecessary physical strain. The dimensions and locations of the chair, screen and input devices are key factors which may influence an individual's bodily alignment, hence the following specific joint angles associated with the use of computers were investigated.

General body angles

When considering the general layout of the computer workstation, chair dimensions and use of the backrest, together with the associated trunk angle and thoracic bend were taken into account. Hochanadel (1995) recommended a trunk angle of 100-110° in order to relieve the pressure on the spine and the load on the erector spinae. In a study by Villanueva *et al*. (1997) they found that the angle formed by thoracic bend was approximately 120° for a variety of screen heights, arguing that a thoracic bend of less than 120° was indicative of a relatively more kyphotic spine. These more neutral joint angles allow for a natural and relaxed seated working posture, and with the computer screen raised, a neck angle closer to 180° can be achieved, which as De Wall *et al.* (1992) found, reduces the muscular effort required to maintain the position of the head by decreasing the flexor moment of the cervical erector spinae (see Figure 25).
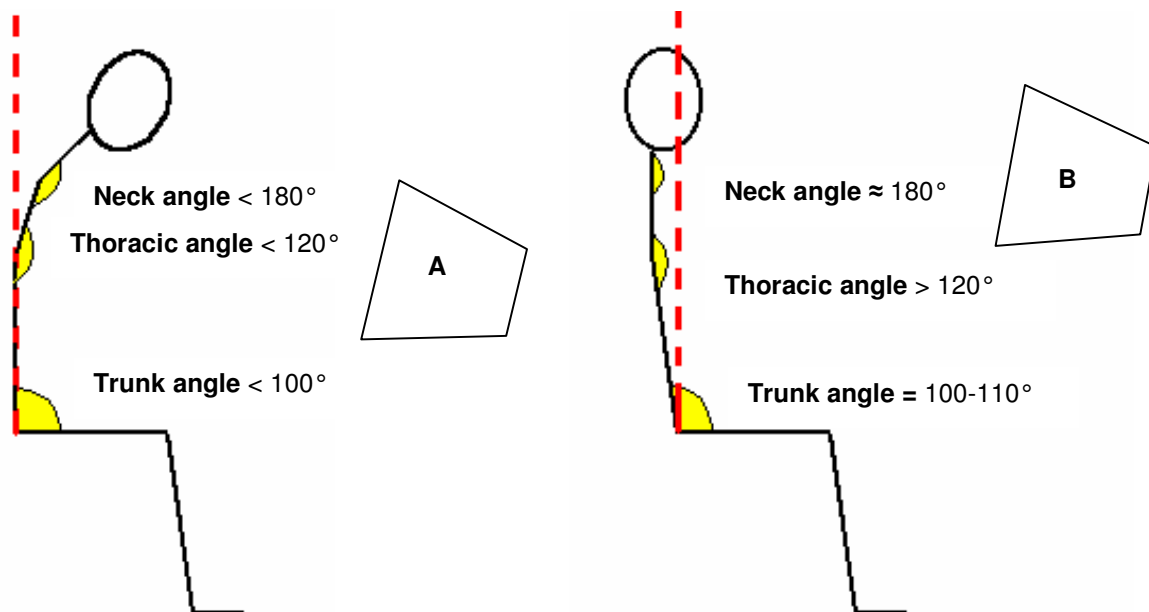
Figure 25: "Awkward" (A), and "ideal" (B) joint angles imposed by a computer workstation.

In all three of the workstations tested, trunk angle was measured from the vertical and was found to be independent of stature as there was no significant difference between the angles obtained for the Short, Medium and Tall operators (Table V). There was, however, a difference between the trunk angles obtained in the Standard, Personalised and Wrist Support workstations when assessing the group as a whole (Table VI). The Standard workstation imposed a 16° trunk angle, while raising the computer screen and adjusting the height of the chair resulted in a 6° increase in trunk angle in the Personalised workstation, and an 8° increase in the Wrist Support workstation. This change in trunk angle is demonstrated in Figure 26. The significant differences ($p<0.05$) between the Standard and Personalised, and the Standard and Wrist Support workstations are evidence of a superior working posture, which Hochandel (1995) contends is associated with a reduction in the intradiscal pressure and a lower level of muscular activity in the trunk muscles.
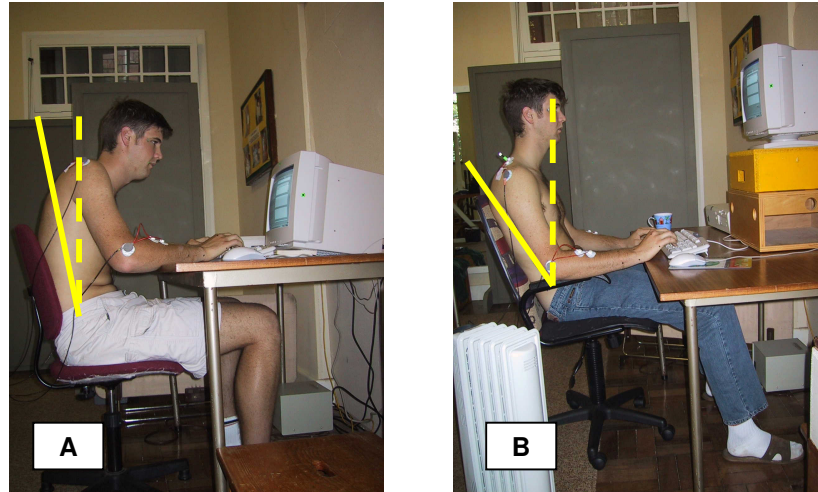
Figure 26: **Comparison of trunk angle of a Tall subject in (A) the Standard workstation, and (B) the Personalised workstation.**

Although stature had no effect on trunk angle, it did have a significant influence on thoracic bend in the Standard workstation (Table V). In this condition, the Short subject group had a mean thoracic angle of 140° which was significantly greater than that of the Medium (129°) and Tall (127°) groups (see Figure 27). Because the chair and monitor were located in a fixed position for this workstation, the height of the monitor, relative to sitting eye height, was lower for the taller subjects. Straker and Mekhora (2000) cautioned that a lower screen forces a forward stooping posture which leads to an elevation in the muscle activity of the thoracic erector spinae.
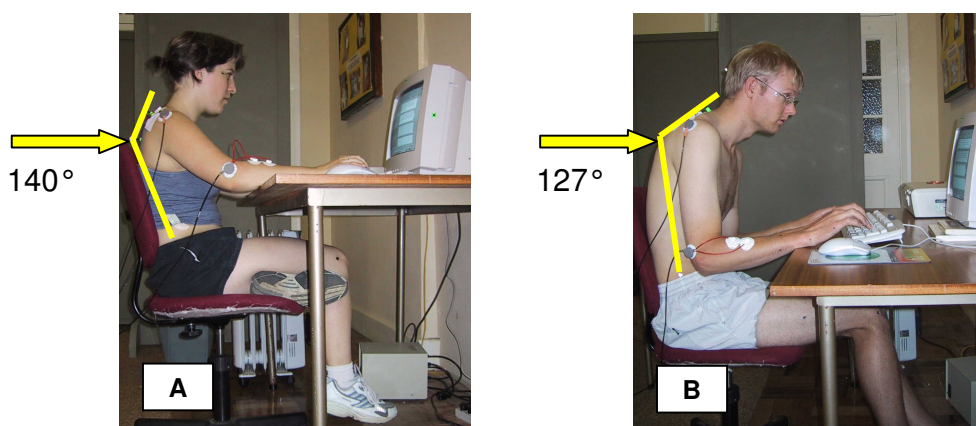
Figure 27: **Comparison of thoracic bend in (A) a Short subject, and (B) a Tall subject while using the Standard workstation.**

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Table V: Body segment angles of Short, Medium and Tall subjects in the Standard workstation.

(means, with SD in brackets)

JOINT ANGLE	Short (°) (n=7)	Medium (°) (n=7)	Tall (°) (n=7)
Trunk angle	14 (7.41)	11 (5.01)	17 (8.84)
Thoracic bend	140 (3.01) * *	129 (4.69) *	127 (6.68) *
Gaze angle	14 (2.76) *	16 (1.72)	19 (2.42) *
Head angle	9 (6.43) *	9 (4.16) *	-2 (6.73) * *
Neck angle	62 (7.73)	64 (5.95)	62 (6.21)
Shoulder angles	5 (2.65)	6 (1.64)	6 (2.59)
Wrist flexion/ extension	14 (3.11)	13 (3.24)	13 (5.41)
Radial/ ulnar deviation (RIGHT)	16 (3.12)	18 (5.21)	17 (3.56)
Radial/ ulnar deviation (LEFT)	18 (6.97)	14 (4.41)	16 (4.22)

* denotes significant difference (p<0.05) between Short and Medium subjects

* denotes significant difference (p<0.05) between Short and Tall subjects

* denotes significant difference (p<0.05) between Medium and Tall subjects

Table VI: Body segment angles of all subjects (n=30) in the three workstations.

(means, with SD in brackets; comparisons made with the Standard (shaded area) workstation)

JOINT ANGLE	Standard (°)	Base	Personalised (°)	Δ	Wrist Support (°)	Δ
Trunk angle	16 (9.88)* *	0	22 (6.76) *	+6	24 (4.84) *	+8
Thoracic bend	132 (6.97)	0	133 (5.62)	+1	133 (5.02)	+1
Gaze angle	16 (2.89)* *	0	-1 (1.32) *	-17	-1 (0.98) *	-17
Head angle	5 (6.89)* *	0	19 (5.80) *	+14	19 (5.73) *	+14
Neck angle	63 (7.98)* *	0	51 (7.05) *	-12	50 (6.18) *	-13
Shoulder angles	5 (3.10)	0	4 (2.57)	-1	5 (3.19)	0
Wrist flexion/ extension	14 (5.40)* *	0	10 (3.32)* *	-4	8 (3.19) * *	-6
Radial/ ulnar deviation (RIGHT)	18 (4.01) *	0	16 (4.82) *	-2	11 (3.96) * *	-7
Radial/ ulnar deviation (LEFT)	17 (5.29) *	0	15 (4.82) *	-2	9 (3.00) * *	-8

* denotes significant difference (p<0.05) between Standard and Personalised workstations
* denotes significant difference (p<0.05) between Standard and Wrist Support workstations
* denotes significant difference (p<0.05) between Personalised and Wrist Support workstations

The overall group mean of the thoracic angles obtained under the three conditions, Standard, Personalised and Wrist Support workstations, were not significantly different (Table VI). However, when comparing the two adjusted workstations with the Standard arrangement it is clear that the personal modifications eradicated the stature related differences between subject groups. The reason for this was that the thoracic forward lean of the Short subject group was reduced to 135°, while that of both the Medium and Tall subjects was increased to 133° in the two personalised workstations. Should the

visual target remain in the same "low" position, it is argued that an increase in trunk angle owing to an improved use of the backrest will in fact decrease the thoracic angle in order for the subject to maintain a focus on this visual target. The personalised workstations in the present study encouraged a more reclined trunk position, and in the case of the Short subjects, the computer screen, relative to chair height was raised by a mean of 112mm, while that of the Medium and Tall subjects was raised by 152mm and 204mm respectively. For the Short subjects, the improved use of the backrest would therefore appear to have had a more substantial influence on thoracic bend than the small increase in screen height, hence the marginal decrease in the thoracic angle. While the taller subjects also adopted a more reclined posture, their thoracic angle was however increased due to the greater increase in the height of their visual target.

Gaze, head and neck angles

Gaze, head and neck angles were assessed in order to investigate the influence of the screen placement on neck posture and head position. Several authors have proposed that a computer screen located below eye level will lead to flexion in the neck (resulting in an unnatural posterior curve), plus a greater gaze and neck angle, and smaller head angle (De Wall *et al.*, 1992; Burgess-Limerick *et al.*, 2000).

The Standard workstation was set up according to the mean dimensions of workstation arrangements in several computer laboratories on Rhodes campus, where the computer screen was simply placed on the desk and its centre was located 180mm above the working surface, and the chair was set at 483mm for all subjects. This configuration forced subjects into adopting marked neck flexion in order to view the screen. In this workstation it was evident that the tall subjects exhibited the greatest degree of neck flexion, which is demonstrated by the differences in gaze and head angle. Although there was no significant difference in the neck angle of the three groups, the tall group had a mean gaze angle of 19° which was significantly greater than the 14° angle of the short subject group due to the awkward alignment of the cervical region of the spine. Further evidence of this unnatural neck posture is demonstrated by the relatively small head angle. Once again the tall subjects maintained the least natural neck postures, as

their average head angle was -2° which is significantly less than the +9° angle of both the Short and Medium subject groups (see Table V). Burgess-Limerick *et al.* (2000) report that any interference with the natural anterior curvature of the cervical spine, caused by the low computer screen, elevates the muscular demand placed on the neck extensors.

When assessing the gaze, head and neck angles at the Personalised and Wrist Support workstations, it is evident that the changes made to the Standard workstation allowed more neutral neck postures. By raising the screen from 180mm above the desk in the Standard workstation, to 419mm and 451mm in the Personalised and Wrist Support workstation respectively, gaze and neck angle were reduced and head angle increased for all subject groups. Using the Standard workstation as a baseline, it is evident that the Personalised workstation resulted in a 17° and 12° decrease in gaze and neck angle respectively, and a 14° increase in head angle (Table VI). These angles indicate a significant decrease in neck flexion ($p<0.05$), and concomitant reduction in neck extensor muscular load as a result of the "ideal" screen position in terms of the musculoskeletal system. An equally improved workstation layout was implemented for the Wrist Support workstation, and consequently there was a similar difference in responses between the Standard and Wrist Support workstations in terms of gaze, head and neck angles (see Table VI). The lack of difference between the Personalised and Wrist Support workstations suggest that raising the screen and chair in order to accommodate the moderate elevation of the forearms with the wrist support encouraged an equally "optimal" neck and head posture as in the Personalised workstation.

Wrist angles

Use of the keyboard and mouse often requires the operator to adopt unnatural working posture for the wrists. As Seth et al. (1999) point out, these awkward postures are the greatest risk factor for the development of cumulative trauma disorders, as they lead to fatigue due to the continuous muscle activation required to maintain the "unnatural" position. In this study, flexion/extension of the wrists, and ulnar/radial deviation were therefore monitored and compared in the three computer workstations. As stature had

no influence on wrist posture (see Table V), the subject responses were pooled and the effects of the workstations are discussed.

Wrist hyperextension

In the Standard workstation, the subjects' wrists deviated 14° (± 3.11 SD) from the neutral position. When this workstation was personalised the relative height of the keyboard was lowered by raising the height of the chair. This change to the workstation reduced wrist deviation in the sagittal plane by 4°. Further improvements to wrist posture were demonstrated by the introduction of the wrist support to the Personalised workstation (see Figure 28). The wrist support elevated the forearms slightly above the level of the keyboard so that the fingers "dropped onto" the keyboard rather than the wrists having to be hyperextended in order for the fingers to reach up to the keys. This mobile support enabled a further 2° reduction in wrist hyperextension (Table VI). The average wrist angle in the sagittal plane was therefore 43% closer to neutral in the Wrist Support workstation compared to the Standard workstation. As illustrated in Figure 29, the angles obtained for wrist hyperextension in the three workstations were all significantly different from one another ($p < 0.05$).
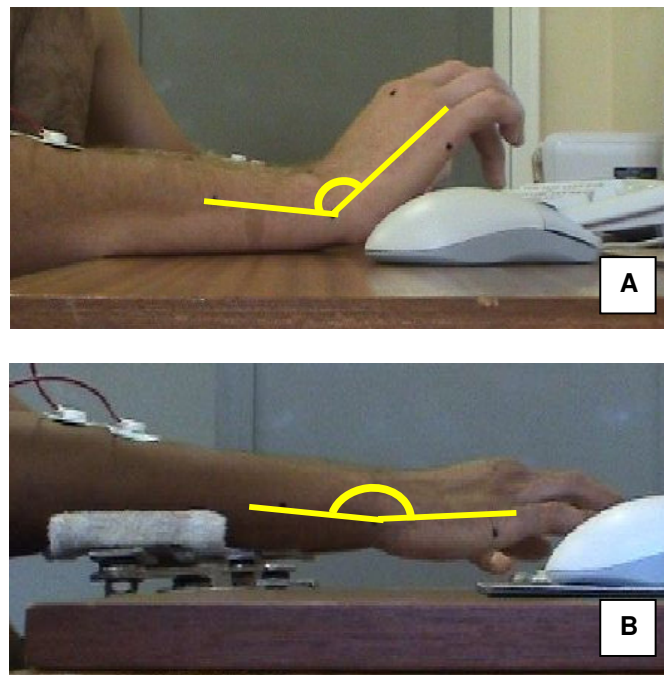
Figure 28: Wrist posture while using the keyboard (A) without the forearm support (hyperextension of the wrist), and (B) with the forearm support (natural alignment of the wrist).
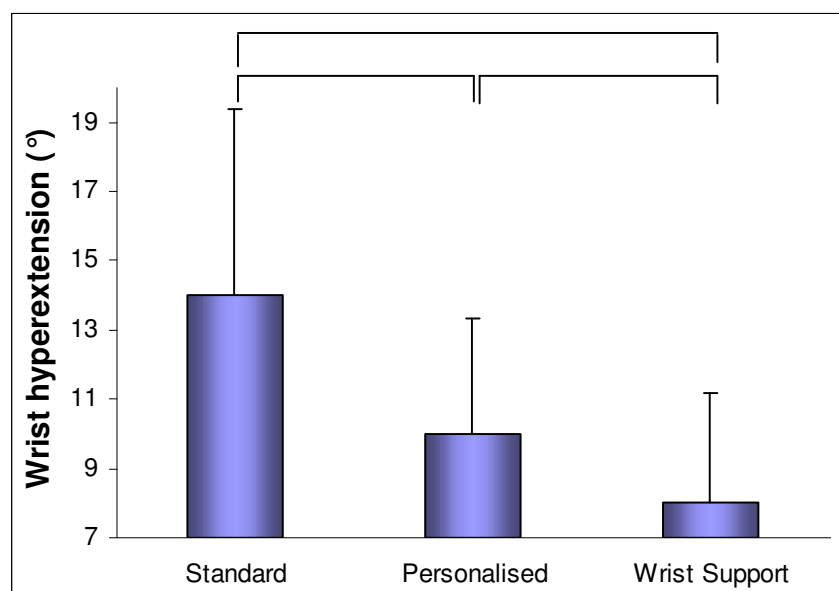

Figure 29: Deviation in wrist position of the overall subject group (n=30) from a neutral position in the sagittal plane for each workstation.

(Bars denote significant difference, p < 0.05)

Radial/ulnar deviation

Gilad and Harrel (2000) suggest that computer users with wider shoulders are forced into a greater degree of ulnar deviation while operating the keyboard as a result of the hands having to be moved a greater distance in order to reach the more central keys. However, in this study it was found that although there was a significant difference between the shoulder breadth of Short and Tall subjects (see Table IV), wrist deviation in the frontal plane was independent of shoulder breadth since there was no difference between the ulnar/radial deviation angles obtained for the Short, Medium and Tall subject groups for both the left and right wrists (Table V). Furthermore, there was no correlation between shoulder breadth and ulnar deviation for both right and left wrists.

The design of the keyboard is directly responsible for ulnar and radial deviation, and as the low-cost changes made while personalising the workstation made no change to the actual keyboard, there was no effect on the degree to which the wrists were positioned in ulnar deviation. However, the Personalised workstation resulted in a significant reduction ($p < 0.05$) in radial deviation (4° and 3° radial deviation for the right and left wrists respectively) when compared to the Standard workstation (5° and 4° radial deviation for the right and left wrists respectively). Due to the fact that the changes in radial deviation were small, the total range of motion (ROM) was not influenced by the Personalised workstation. The mobile wrist support, however, enabled the users to mobilise their entire upper extremity with minimal effort, while accessing different parts of the keyboard and/or mouse. When comparing the Wrist Support to the Standard workstation, ulnar deviation was reduced by 30.8% in the right wrist and 46.2% in the left wrist. In terms of radial deviation for both the right and left wrists, the Wrist Support workstation allowed for the most neutral wrist posture (2° radial deviation for both wrists). The Wrist Support workstation therefore allowed for a significant improvement ($p < 0.05$) of 7° in the right wrist and 8° in the left wrist for average total wrist ROM in the frontal plane (see Table VI). These changes in wrist deviation are illustrated in Figure 30.
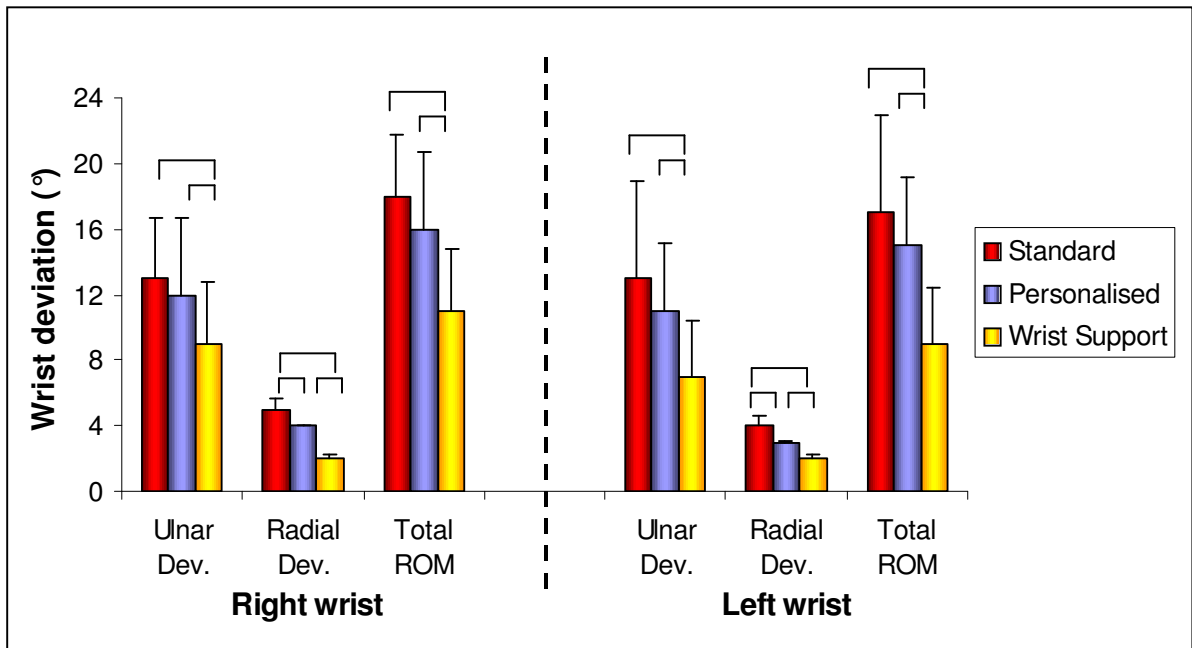
Figure 30: **Average range of ulnar and radial deviation of the entire subject group (n=30) in all three workstations.**

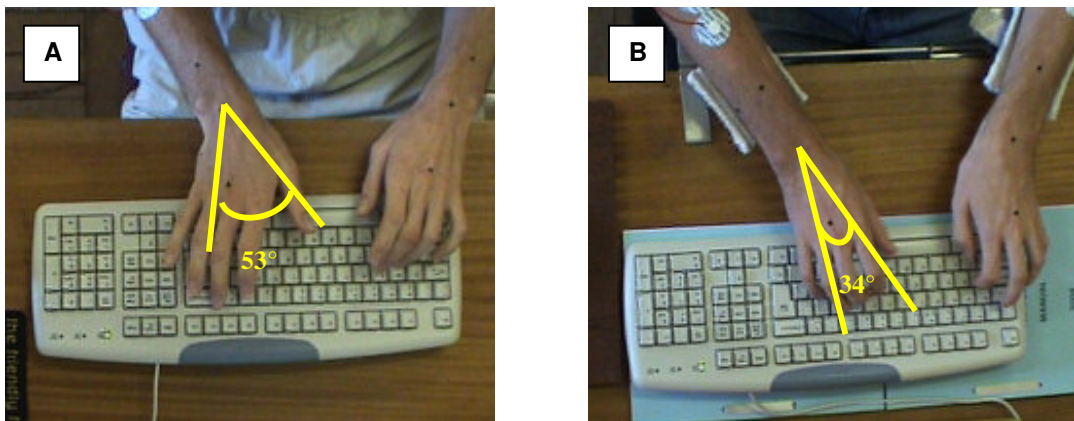(Bars denote significant difference between workstations, p<0.05)

Figure 31: **Maximum range of ulnar and radial deviation while using the keyboard (A) without the forearm support, and (B) with forearm support.**

The maximum total range measured for an individual in the Standard workstation was 53°, which encompassed 36° of ulnar deviation to 17° of radial deviation. The wrist rest implemented in Condition 3 reduced this extreme range to a maximum of 34°, which comprised 25° of ulnar and 9° of radial deviation. Figure 31 demonstrates the obvious decrease in the maximum total range of ulnar/radial deviation in the Wrist Support workstation compared to the Standard workstation.

Gilad and Harrel (2000) recommended that the natural operating zone of the wrists is 15° wrist extension and 20° wrist flexion, with less than 20° of either ulnar or radial deviation. Although the mean wrist angles obtained for the subjects in the present study were within this "zone" in all three workstations, the maximum range (36° ulnar deviation to 17° radial deviation) demonstrates the occurrence of wrist postures outside this natural operating zone. As Werner et al. (1997) stated, wrists which are maintained in a posture that is not neutral leads to elevated fluid pressure within the carpal tunnel. Any reduction in wrist flexion/extension and/or radial/ulnar deviation will therefore reduce the risk of developing carpal tunnel syndrome.

Shoulder angles

As a result of the varying demands and/or tasks carried out by the left and right hands while operating a keyboard and/or mouse, there is often a certain degree of asymmetry between the position of the shoulders. This was evident in the Short, Medium and Tall subjects in all three of the workstations. On average there was 5° discrepancy between the shoulders, with the right shoulder generally being nominally elevated and the left shoulder marginally depressed. Although this discrepancy in shoulder position may be influenced by task demands, no significant difference was found between the four different tasks carried out in the performance test. Furthermore, there was no difference between the three workstations in terms of the discrepancy in shoulder position.

MUSCULAR ACTIVITY

It is universally recognised that awkward and static working postures are responsible for a high number of cumulative trauma disorders (Grieco, 1986; Thorn et al., 2002), and as noted by Mathiassen et al. (2003), these unnatural working postures are reflected by elevated and unfavourable levels of muscle activity. Electromyography was therefore used to determine whether changes made in order to personalise a Standard workstation, as well as the addition of a wrist support, were in fact beneficial to the user. Because of the vast variability in the maximum muscular capacity of the subjects, demonstrated in Table VII, the muscle activity data were assessed as a percentage of Maximum Voluntary Contraction (MVC) in order for interindividual comparisons to be made.

Table VII: MVC data obtained for all subjects (n=30).

(mean, with SD in brackets)

	Right	Left
Upper trapezius MVC (µV)	436.57 (300.25)	376.38 (275.58)
Wrist Extensor MVC (µV)	553.27 (255.85)	435.83 (202.57)

Gao et al. (1990) suggest that varied use of different input devices results in different demands being placed on the operator. Therefore, in the present study, the battery of tests performed by the subjects during data collection consisted of five different tasks. However, the various tasks had no significant impact on the level of activity in either the right and left upper trapezius muscles in any of the three computer workstations. This lack of significant difference between the percentages of MVC obtained during the different tasks suggests that varied use of input devices may influence some responses, but the activation of upper trapezius load in this project was independent of the task, and the data were therefore pooled for further analyses. Although insignificant, it was interesting to note that percentage MVC for both right and left upper trapezius

musculature, in all three of the workstations, was highest for the typing task and lowest for the mouse task.

Contrary to the upper trapezius, where there is continuous and static "holding" of the upper extremity in a posture such that the arms are flexed at the elbow and resting on the working surface throughout the entire battery of tests, the activity of the hands varies according to the task being carried out. The EMG response of the wrist extensors is reflective of the dynamic "working" load carried out by the hands and fingers during the various sections of the performance test, and because the responses are dependent on the type of work carried out, EMG data collected during each task are presented and assessed separately. However, there was no difference between the wrist extensor EMG responses of the stature based groups, and the data were therefore collectively assessed for all subjects. The similar responses of the subject groups suggests that the risk of developing a CTD as a result of wrist flexion/extension is independent of stature.

Upper trapezius EMG

The mean MVC of the right and left upper trapezius was 436.6µV and 376.4µV respectively (Table VII). Twenty-eight of the 30 subjects were right-hand dominant, a probable reason for the higher MVC recording for the right upper trapezius. Although the task demands were different for the right and left upper extremities, there was no difference between the percentage MVC of the right and left upper trapezius during any of the work tasks performed at the three workstations. This suggests that the same relative effort was required by both sides throughout the performance test in order to sustain the required 'static' positioning of the upper extremities.

As the Standard workstation was set up to accommodate the "average" computer operator, it was expected that subjects with extreme anthropometric characteristics would be most affected by the workstation, and the load placed on the upper trapezius would therefore be a higher percentage of MVC, since these subjects were required to adopt the most unnatural working postures in order to utilise the workstation. This was clearly demonstrated by the upper trapezius EMG results (see Table VIII). The

percentage MVC of the right and left upper trapezius muscles of the Short and Tall subjects were significantly higher than those of the Medium subjects ($p<0.05$). For the right upper trapezius, the percentage MVC of the Short and Tall stature groups were 3.3 and 2.9 times higher than that of the Medium group (4.6% MVC). There was a similar response in the left upper trapezius where the percentage MVC of the Short and Tall groups were 2.9 and 2.1 times higher than that of the Medium subject group (4.0% MVC).

Table VIII: Upper trapezius EMG responses for the three subject groups in each of the three workstations.

(mean % MVC, with SD in brackets)

		Standard (% MVC)	Personalised (% MVC)	Wrist Support (% MVC)
Short (n=7)	**Right**	15.1 (8.22)	7.5 (4.40)	5.6 (3.63)
	Left	11.6 (7.09)	8.1 (5.41)	5.3 (3.31)
Medium (n=7)	**Right**	4.6 (3.19)	2.6 (1.94)	3.9 (2.21)
	Left	4.0 (2.26)	1.8 (1.17)	2.7 (1.88)
Tall (n=7)	**Right**	13.4 (8.25)	5.1 (4.75)	7.3 (4.53)
	Left	8.1 (4.76)	3.4 (3.09)	5.1 (4.43)

] denotes significant difference ($p<0.05$) between subject groups (Right upper trapezius)
] denotes significant difference ($p<0.05$) between subject groups (Left upper trapezius)

Although the muscular load was significantly reduced (p<0.05) during testing at both the Personalised and Wrist Support workstations (see Figure 32), differences between the stature groups still existed (Table VIII). In the Personalised workstation this difference was evident in the right upper trapezius where the muscle activity of the Medium group was 2.6% MVC. The muscle load in the right upper trapezius of the Short and Tall groups was 7.5% MVC and 5.1% MVC respectively. However, the left upper trapezius activity of the Medium (1.8% MVC) and Tall (3.4%MVC) groups were not significantly different, but that of the Short group (8.1% MVC) was significantly higher (p<0.05) than the other two subject groups.

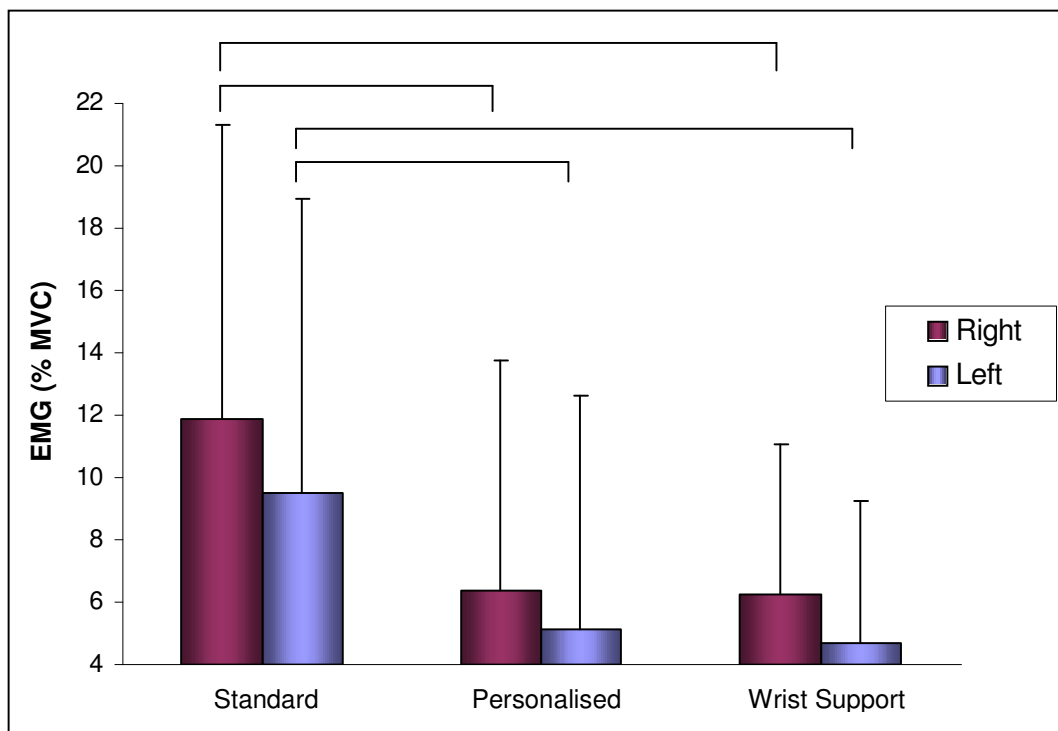**Figure 32: Upper trapezius EMG responses of the total group (n=30) in each of the three workstations.**
(Bars denote significant difference, p < 0.05)

The implementation of the wrist support did not further reduce the percentage MVC of the upper trapezius for the three subject groups or for the group as a whole. It did, however, eradicate some of the stature related differences (Table VIII), as well as offer a

significant improvement on the Standard workstation (Figure 32). The percentage MVC of the left upper trapezius of the Short subject group (5.3% MVC) was still significantly higher than that of the Medium subject group (2.7% MVC), and the load placed on the right upper trapezius of the Tall operators (7.3% MVC) was significantly greater than that of the Medium subjects (2.7% MVC). The reduction in the number of significant differences between the subject groups suggests that the Wrist Support workstation offered an improved layout specifically to subjects of extreme stature.

In a recent study by Thorn et al. (2002) it was suggested that cumulative trauma disorders can be sustained when static work muscle activity is as low as 5% MVC. In the present study the Standard workstation resulted in an individual obtaining a maximum of 56.1% MVC. However, when assessing the right and left sides together, an average load of 10.7% MVC was imposed upon the upper trapezius of the group as a whole (n=30). The average of 5.8% MVC and 5.6% MVC measured in the Personalised and Wrist Support workstations respectively demonstrates a significantly reduced muscular load (p<0.05), and although the risk of CTD development was not eliminated, it was diminished to a large degree.

Wrist extensor EMG

Although the demands of the tasks required dissimilar use of the right and left hands, there was no difference between the load placed on the right and left wrist extensors (extensor carpi radialis, extensor carpi ulnaris, extensor digitorum communis). However, the muscle activity was marginally greater in the right wrist extensor for the editing, mouse and numeric tasks, whereas for the typing task the left wrist extensor was exposed to a marginally higher percentage MVC (see Figure 33). A possible explanation for this could be that while the actual workload carried out by each hand was the same during typing, the majority of the subjects were right hand dominant and as a result the MVC for the right wrist extensors was 27.0% greater (553.3µV) than that of that left extensors (435.8µV). Relative to maximum muscular capacity the left extensor therefore experienced a marginally larger load, and as a result it could be argued that the left wrist is at a higher risk of developing a musculoskeletal disorder.
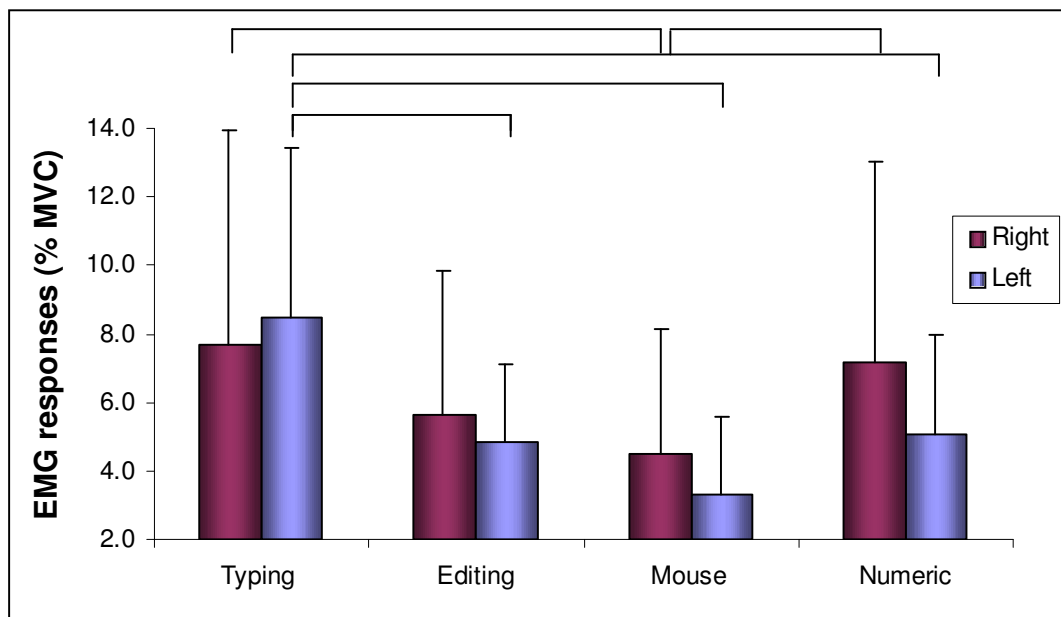
Figure 33: Variations in wrist extensor EMG responses according to task performed.

(Bars denote significant difference between tasks, p<0.05)

When analysing the tasks independent of the workstation (Figure 33), it is evident that the typing task imposed the highest load on both the right and left wrist extensors (7.7% MVC and 8.5% MVC respectively). This was due to the fact that typing requires continuous and repetitive use of all the fingers while operating the keyboard. Furthermore, this was the only task that was highly dependent on the use of both hands since the other tasks were carried out mainly by the right hand while the left hand was used to a lesser degree. The numeric task imposed a high level of muscle activity on the right wrist extensor (7.2% MVC) as a result of the flexion and extension of the right wrist and fingers required to operate the number pad on the right of the keyboard. The left thumb was generally used to strike the spacebar during numerical data entry. The editing and mouse tasks resulted in the lowest wrist extensor EMG responses. During the editing task there was intermittent and varied use of the fingers as the two input devices, keyboard and mouse, were both used while performing this task. Although not significant, a marginally higher EMG level was recorded in the right wrist extensor (5.7% MVC) compared to the left (4.7% MVC), since it was used to operate the mouse as well

as the editing keys and arrows, in addition to the typing keys in this section. The mouse task required flexion and extension of only the right index finger in order to depress and release the mouse button, hence an activity level in the right wrist extensor of 4.5% MVC, while the left hand remained 'unused' to execute this particular sub-task and resulted in an activity level of only 3.3% MVC in the left wrist extensors.

Table IX demonstrates the grouped results of all tasks carried out in each of the three workstations. Neither the right nor the left wrist extensors were affected by the changes made to the Standard workstation. Although the wrist support encouraged a significantly improved wrist posture, in terms of wrist extension, the position of the support still required an active effort of the wrist extensors to hold the hands in a neutral position above the keyboard. While the values recorded for right and left wrist extensor EMG were not excessive, if these muscle activity levels were maintained for a prolonged period of time, they would expose the individual to the risk of developing a CTD.

Table IX: Wrist extensor EMG for all subjects (n=30) during the execution of the work tasks in each of the workstations.

(mean % MVC, with SD in brackets)

	Right (% MVC)		Left (% MVC)	
Standard	6.3	(4.73)	5.6	(4.49)
Personalised	6.4	(5.08)	5.0	(3.98)
Wrist Support	5.8	(5.25)	5.1	(3.66)

PERCEPTUAL RESPONSES

While the biophysical and muscle activity responses of the body to changes in any work situation are the basis of any rigorous assessment, it is essential to also consider the subject's personal perceptions of these changes. As Charteris et al. (1976) point out,

human beings are a complex species and they therefore need to be addressed with a holistic approach.

Body discomfort

Body discomfort is an important factor which enables one to assess an individual's perceptions of the demands imposed upon them (Corlett and Bishop, 1976). In this case the assessment of body discomfort gave an indication of the awkwardness of posture and the resultant musculoskeletal load imposed by the three computer workstations, thereby assisting with the determination of CTD risk associated with the different workstation components. Subjects were required to rate each body segment on a scale ranging from 0 (No Discomfort) to 5 (Extreme Discomfort) on completion of each performance assessment.

The subjects' perceptions of discomfort of 15 body parts were assessed (see Figure 23, p 74). When assessing the body discomfort reported for the individual body segments, Table X demonstrates the reduction in the number of segments reported to have experienced some level of discomfort in the two personalised workstations. In the Standard workstation there were a total of 312 reports of discomfort with a mean intensity ranging from 1.1 to 2.1. On average each subject therefore claimed discomfort in 10.4 body segments. In the Personalised workstation the total was reduced to 157 reports (5.2 body segments per subject) ranging from 1.0 to 2.0. The Wrist Support workstation also showed an improvement on the Standard workstation. The total number of reports was reduced to 197 (6.6 body segments per subject) with an intensity ranging from 1.0 to 1.8. These data demonstrate a 49.6% and 36.9% reduction in the number of reports of discomfort in the Personalised and Wrist Support workstations respectively, with the intensity of the discomfort being lowest in these two personalised workstations.

Table X: Body discomfort ratings of the individual body segments for the entire subject group (n=30).

	Standard		Personalised		Wrist Support	
	N	**I**	**N**	**I**	**N**	**I**
Neck	25	2.1	14	1.4	13	1.2
Upper Back	24	2.1	12	1.3	16	1.4
Middle Back	16	1.9	6	1.2	6	1.2
Lower Back	19	2.0	11	1.3	9	1.1
Buttocks	12	1.3	7	1.3	6	1.2
Thigh	10	1.4	6	1.7	3	1.0
Knee	5	1.4	2	1.0	2	1.0
Lower Leg	7	1.4	3	1.0	4	1.0
Foot	9	1.4	1	2.0	3	1.0
Right Shoulder	25	2.0	14	1.4	16	1.8
Left Shoulder	21	2.0	10	1.6	17	1.8
Right Upper Arm	8	1.9	4	1.0	7	1.3
Left Upper Arm	7	1.3	4	1.0	7	1.1
Right Elbow	9	1.1	2	1.0	5	1.2
Left Elbow	9	1.1	2	1.0	6	1.2
Right Forearm	18	2.1	16	1.3	13	1.8
Left Forearm	14	1.6	13	1.4	15	1.8
Right Wrist	18	1.7	6	1.3	12	1.5
Left Wrist	18	1.4	8	1.3	12	1.5
Right Hand/Fingers	19	1.6	8	1.4	11	1.5
Left Hand/Fingers	19	1.6	8	1.4	14	1.6
TOTAL	**312**		**157**		**197**	

N = Number of ratings for each area; I = mean intensity of discomfort for each area

In the Standard workstation the body segments with the highest incidence of discomfort include the neck, upper back and shoulders. All Short and Tall subjects reported discomfort in the neck, while only 66.7% of the Medium subjects experienced this discomfort. This is indicative of the Standard workstation being designed for operators of "average" morphology. The neck and back discomfort is attributed to the prolonged and static neck and upper back flexion in order to view the "low" monitor. With the computer screen raised in the two personalised workstations there was a concomitant reduction in spinal flexion thereby decreasing the number of body discomfort reports in the neck by 11 and 12, and in the upper back by 12 and 8 in the Personalised and Wrist Support workstations respectively. Fifty percent of the Tall and 42.9% of the Short subjects did, however, still report some discomfort in the neck in the two personalised workstations, and 46.7% and 40.0% of the Medium subjects felt this discomfort in the Personalised and Wrist Support workstations respectively. The intensity of this discomfort was, however, reduced from 2.1 in the Standard workstation to 1.4 and 1.2 in the Personalised and Wrist Support workstations. De Wall et al. (1992) identified the musculoskeletal benefit of increasing the screen height in order to reduce the flexor moment of the cervical spine and thereby decrease muscular effort required to stabilise the head in a poorly aligned posture, and the associated discomfort.

The occurrence of discomfort in the shoulders in the Standard workstation is reflected in the relatively high EMG recordings obtained for the upper trapezius musculature. As Grieco (1986) stated, prolonged muscular tension leads to pain and discomfort which in turn is likely to lead to the development of a CTD. Although there was a significant difference between the upper trapezius EMG recordings for the three subject groups in the Standard workstation, they all reported similar shoulder discomfort. Seventy-five percent of the Short, 76.7% of the Medium and 78.6% of the Tall subjects experienced some form of shoulder discomfort, and the mean intensity for this discomfort was 2.2, 2.0 and 2.2 respectively. By raising the height of the chair in the Personalised and Wrist Support workstations the relative height of the keyboard was lowered. This prevented subjects from being forced to elevate their shoulders in order for their hands to comfortably reach the keyboard. Together with the reduced upper trapezius EMG levels,

there was a 44.0% and 52.4% decrease in the number of reports of right and left shoulder discomfort in the Personalised workstation, and a 36.0% and 19.0% reduction in the Wrist Support workstation.

Incidence of body discomfort in the middle and lower back were also reduced in the Personalised workstation by 10 and 7, and both by 10 in the Wrist Support workstation. These data support the suggestion by Hochanadel (1995) that a more reclined seated posture, demonstrated by an increased trunk angle, and enhanced utilisation of the back rest results in a lower load placed on the erector spinae and therefore a decrease in musculoskeletal discomfort.

Other areas where the adjustments made to the Standard workstation demonstrated a diminished incidence of body discomfort include the wrists and hand/fingers. The Personalised workstation reduced the number of reports of discomfort in the right and left wrists by 67.7% and 55.6%, while the Wrist Support workstation resulted in a 33.3% reduction for both wrists. The Personalised workstation allowed for a 4° improvement in terms of wrist flexion/extension. This more neutral wrist posture is reflected by the reduced wrist and hand/finger discomfort. Although the wrist support offered a further 2° improvement in terms of wrist flexion/extension, as well as a significant decrease in ulnar/radial deviation, the incidence of wrist and hand/finger discomfort in this workstation was higher than in the Personalised workstation. A possible explanation could be the lack of familiarity with the device and with the fingers "dropping" onto the keyboard. An argument put forward by Aarås et al. (1998) suggested that the initial implementation of a workstation design often leads to an initial increase in ratings of discomfort followed by a reduction as the user becomes accustomed to the new design over time. This occurs because individuals tend to adjust to postures which they are used to and which are sometimes anatomically unnatural. As a result they initially tend to feel more comfortable in these postures than in the adjusted work postures.

All of the body segments showed a reduction in the incidence of body discomfort with the personalised adjustments made to the Standard workstation. A simple adjustment

made to the height of the chair was directly related to the decrease in lower extremity discomfort which, in turn, positively enhanced the alignment of the trunk and the posture of the entire upper extremity. These data suggest that the general seated working postures of the subjects in this study were substantially improved in the personalised workstations.

In terms of intensity, the body discomfort results indicate that the Standard workstation gave rise to the highest level of discomfort (see Figure 34). In this workstation 50.4% of the body segments were reported to be of "No Discomfort" compared to the 75.1% and 68.7% of the body segments in the Personalised and Wrist Support workstations respectively. Concurrently, 49.6%, 24.9% and 31.3% of the ratings in the Standard, Personalised and Wrist Support workstations were therefore categorised into an area of some discomfort. In the categories of some discomfort (1-Mild Discomfort – 5-Extreme Discomfort) the greatest percentage was exhibited by the Standard workstation followed by the Wrist Support workstation and lastly the Personalised workstation. For example, while less than 8% of the ratings in the Personalised and Wrist Support workstations reported any "Moderate Discomfort", 14% of the Standard workstation ratings fell into this category. This demonstrates a decrease in the perceived ratings of discomfort as a result of the workstation layout in the Personalised and Wrist Support workstations compared to the Standard workstation, indicating that these workstations promoted a more natural working posture.
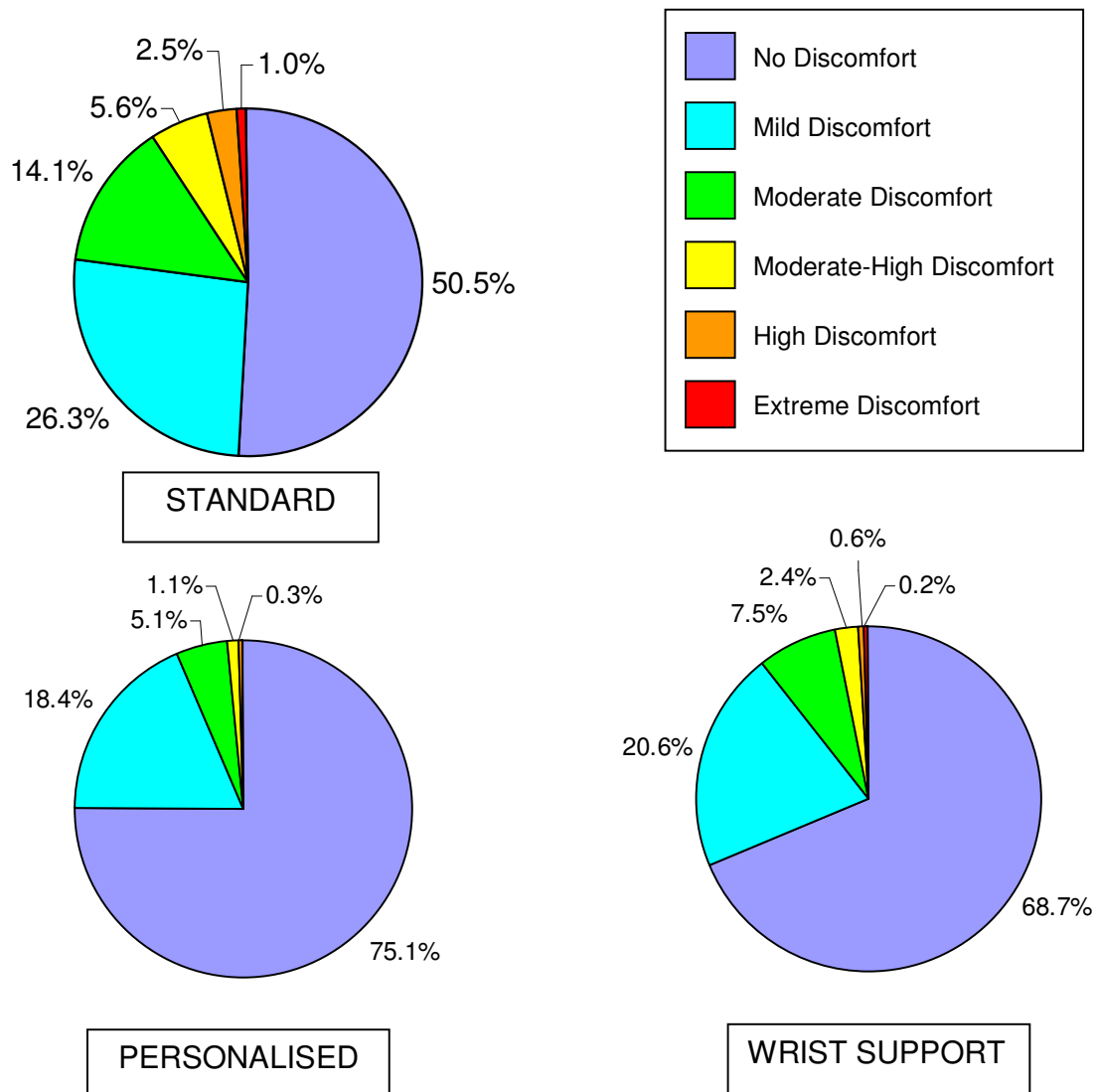
Figure 34: Percentage of body discomfort ratings in the different rating categories.

It is well known that different individuals respond differently to discomfort, and as reported by Helander and Zhang (1997) some subjects subconsciously adjust their posture before the onset of noticeable discomfort. This was especially evident in the Standard workstation, and from general observations there did appear to be a reduction in the amount of in-chair movements in the personalised workstations thus signifying more natural and comfortable work postures.

Visual discomfort

When determining the "ideal" placement of the computer screen, either the visual system or the musculoskeletal system is often compromised (Burgess-Limerick et al., 2000; Kim et al., 2003b). The focus of the present study was to compare a low screen where Ankrum (1997) contends that the visual system is best accommodated, and a high screen which, according to De Wall et al. (1992), allows for a more natural cervical posture. The postural benefits of a monitor positioned so that the centre of the screen is aligned with eye level have already been demonstrated (see p 86). Using a visual discomfort questionnaire, the effect of screen height on the visual system was assessed.

Seven characteristics of visual fatigue were analysed using a four-point rating scale (see Appendix B). As can be seen from Figure 35, in all three of the workstations the majority of the visual symptoms were classified as "Not at all". However, when the computer screen was lowest in the Standard workstation, 31.4% of the visual fatigue ratings exhibited some level of visual discomfort, while in the two personalised workstations, where the height of the monitor was significantly raised, the percentage of ratings of some visual discomfort decreased to 21.9% and 23.3% in the Personalised and Wrist Support settings. These findings are contrary to those of several authors (Tyrrell and Leibowitz, 1990; Ankrum, 1997; Burgess-Limerick et al., 2000) who associated a high screen with increased visual symptoms. In the "Mild", "Irritating" and "Extreme" rating categories the greatest percentages of perceptions of visual discomfort were all reported while working at the Standard workstation. While the relative height of the computer screen was the same in the Personalised and Wrist Support workstations, the visual discomfort in the Personalised workstation was the lowest. This may relate to one of the limitations of perceptual assessments, for as Mekhora et al. (2000) point out, subjects are sometimes psychologically influenced when placed in unfamiliar situations. For example, if because of lack of familiarity, a subject did not like the wrist support, their negative perceptual responses may have been exacerbated.
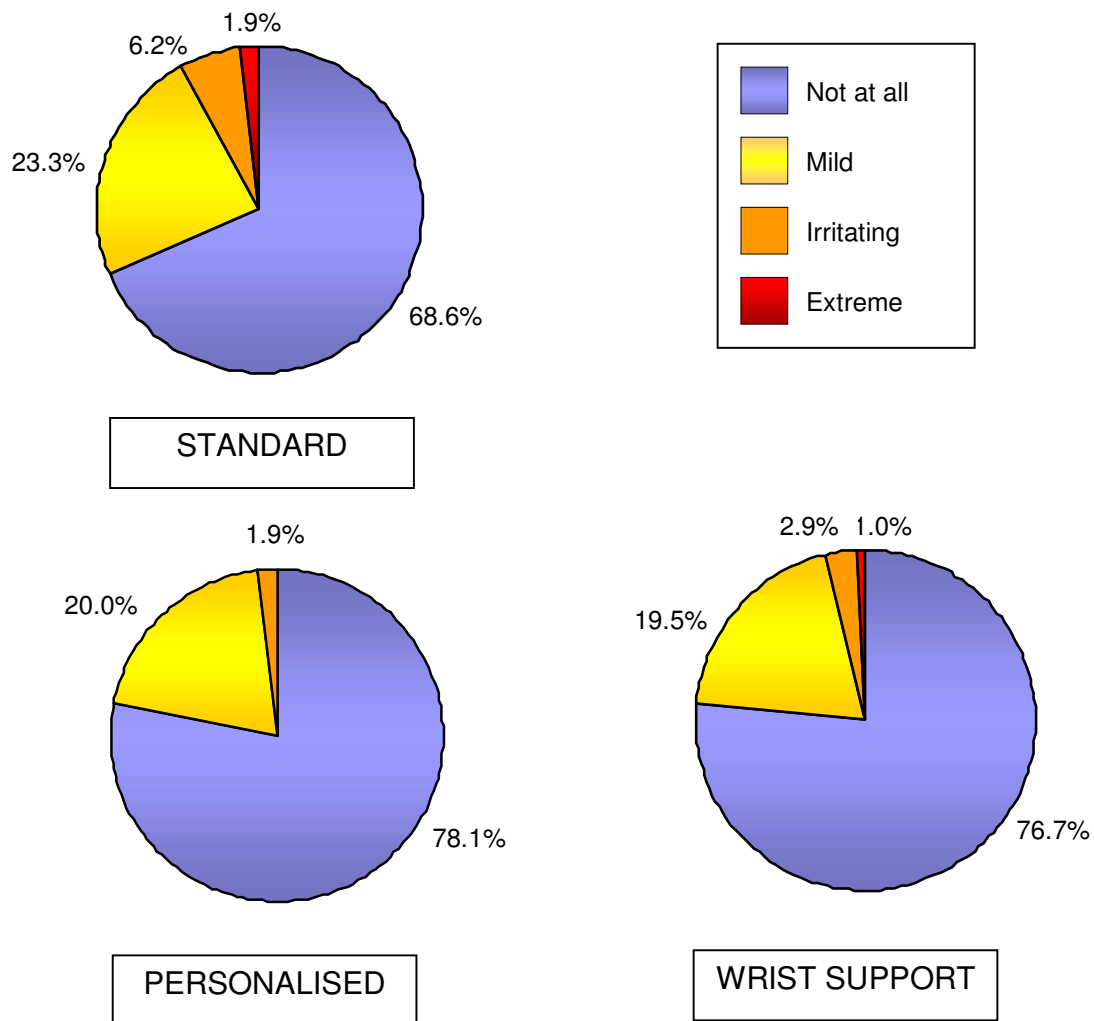
Figure 35: Percentage of visual discomfort ratings in the different rating categories for each of the three workstations.

While the difference in visual symptoms between the workstations was minimal, within the rating categories of some discomfort (Mild, Irritating, Excessive), the Standard workstation exhibited the greatest number of reports for all visual symptoms except for "itchy" eyes where the highest number of reports was in the Personalised workstation (Figure 36). "Tired" eyes appear to be the most common symptom experienced by computer operators with 58.9% of the ratings for this symptom, for all workstations assessed together, being of some discomfort. Seventy-three percent of the subjects in

the Standard, 46.7% in the Personalised and 56.7% in the Wrist Support workstations experienced some intensity of "tired" eyes. "Tearing" eyes, on the other hand, was experienced by the least number of participants. Collectively, in all three workstations, only 6.7% of the responses demonstrated "tearing" eyes. "Tearing" eyes was reported by 10.0% of subjects in the Standard, 6.7% in the Personalised and 3.3% in the Wrist Support workstation.
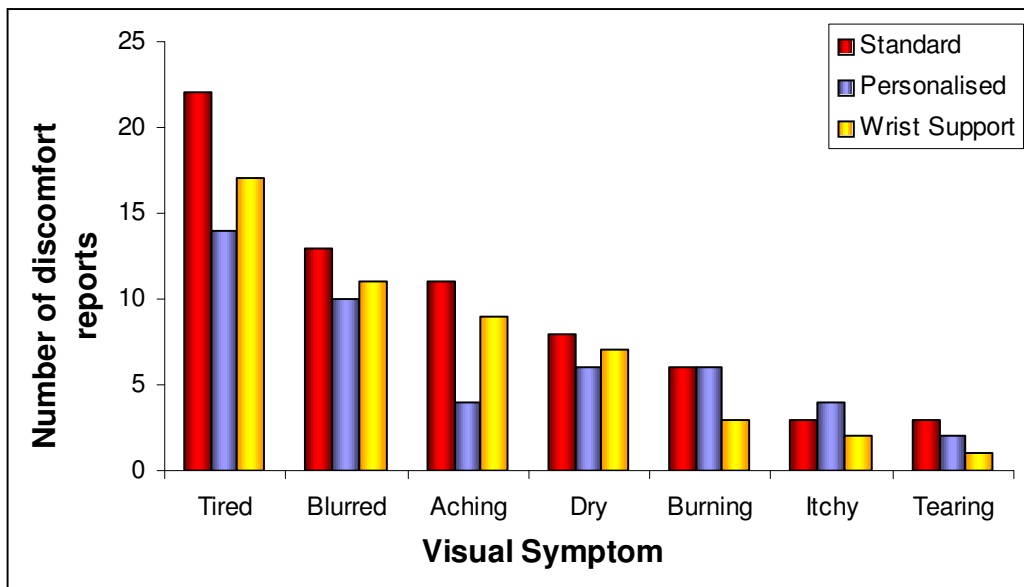
Figure 36: Number of reports of visual symptoms in each workstation.

It is evident that there were not only postural benefits, such as improved postural angles, reduced muscular demand and a decrease in the body discomfort associated with an increase in the height of the computer screen to eye level, but in contrast to the findings of Ankrum (1997) there was a concomitant decrease in the number of reports, as well as the intensity, of visual discomfort in the present study.

Workstation perceptions

Although humans have the ability to adjust to changes in computer workstation layout, they often compromise their natural bodily alignment to do so. Furthermore, computer operators tend to accept the layout and expect that with time their bodies will adjust to the altered demands imposed upon them. It is therefore important that the subjects' perceptions of the workstation design be taken into consideration, and that they be encouraged to make a conscious evaluation of the different workstation components. The subjects' perceptions of the three workstations tested in the present study are depicted in Table XI.

Because the personalised adjustments made to the Standard workstation accounted for stature, there was no difference in the workstation perceptions of the three subject groups in the two personalised workstations. However, the Standard workstation, which was set up according to an "average" person's morphology, resulted in 69.2% of the Medium compared to the 57.8% of Short and 46.4% of Tall subjects perceiving the workstation dimensions as "Fine". This supports the fact that extreme subjects are not accommodated in Average Standard workstations.

Chair

By altering the height of the chair, each subject's general seated posture was adjusted. In some instances the chair was adjusted in order to accommodate the position of the keyboard since the desk was of a fixed height. In some of these cases the chair was then too high for a few of the shorter subjects and a footrest was therefore introduced (see Figure 37). When discussing chair height in this section it refers to the difference in height from the seat pan to the resting surface of the feet thereby taking the footrest into consideration. The workstation dimensions are presented in Table III (p 58).

Figure 37: Use of a footrest to ensure full support of the feet.

In the Standard workstation 18 of the 30 subjects were content with a chair height of 483mm, with 37.5% of the Short, 80.0% of the Medium and 42.9% of the Tall rating this workstation dimension as "Fine". This confirms that the Standard workstation was best suited to accommodate people of "average" morphological characteristics such as those in the Medium subject group. Fifty percent of the Short subjects and the remainder of the Medium and Tall subjects felt that the chair was too low in relation to the keyboard.

In the two personalised workstations the mean height of the chair was lowered slightly for the Short subjects. This alteration to the workstation resulted in 100.0% of the Short subjects rating this workstation dimension as "Fine". A similar improvement in the perceptions of chair height were demonstrated by the Medium and Tall subject groups. While the chair was raised in both the Personalised and Wrist Support workstations for the Medium and Tall subjects, there was no significant difference between the chair height in these two workstations. A consistent 93.3% of the Medium subjects perceived the chair height to be satisfactory. However, 14.3% of the Tall subjects rated the Personalised chair height as "Too high" while in the Wrist Support workstation 100.0% of the Tall subjects rated it as "Fine" even though this mean seat height was marginally higher than in the Personalised set up (Table XI). In the Personalised workstation the

Tall subjects may have been rating the chair height according to their upper extremity posture rather than their general seated posture. The wrist rest raised the forearm off the desk slightly and as a result subjects may have felt that their arms were no longer being lowered too far to the keyboard, thus alleviating their perception of the chair being too high.

Computer screen

The height of the computer screen was raised for all subjects when personalising the Standard workstation. Because the height of the chair would influence the height of the monitor relative to sitting eye height, screen height in this discussion, refers to the difference between the centre point of the screen from the floor and the height of the seat pan.

The height of the screen in the Standard workstation was 460mm from the seat pan. At this height only 12.5% of the Short and 26.7% of the Medium subjects were satisfied with the screen, while the remaining 83.3% of all 30 subjects perceived the screen as being too low in this position. Personalising the Standard workstation resulted in the screen being raised by a mean of 125mm for the Short, 157mm for the Medium and 209mm for the Tall subjects. Assessing the group as a whole (n=30), the percentage of subjects content with the adjusted screen height increased from 16.7% in the Standard workstation to 73.3% in the Personalised workstation, and 83.3% in the Wrist Support workstation, and none of the subjects perceived the adjusted computer screen heights as being too low. However, 26.7% and 16.7% of the 30 subjects did rate the screen as "Too high" in the Personalised and Wrist Support workstations respectively. Although subjects were given some time to habituate to the different workstation layouts, the raised computer screen was very different to any of their personal computer workstations. As pointed out by Straker and Mekhora (2000), computer operators become accustomed to their personal computer workstations, and as a result their muscle length and strength, ligament length, and even bone structure may develop to suit their monitor height. An ergonomically sound workstation may therefore be perceived as different, and therefore unsatisfactory to the operator initially.

Screen position was rated as either being "Too close", "Fine" or "Too far", and screen tilt was rated as "Too much towards you", "Fine" or "Too much away from you". Although neither of these components were changed for any of the workstations, the subjects' perceptions of them were altered depending on the height of the screen. With the monitor positioned at a lower height, 20.0% of the total subject group would have preferred the screen to be closer. When the computer screen was raised in the personalised workstations, 93.3% of the subjects rated the horizontal position of the screen as "Fine", and only 1 of the 30 subjects in the Wrist Support workstation would have preferred it to be slightly closer. It would therefore appear that a visual focus which requires a downward gaze is preferred when the focal point is closer to the subject.

In terms of screen tilt, 30.0% of all subjects in the Standard workstation perceived the screen as being tilted towards them too much (see Figure 24a, p 75), while the remainder thought it was "Fine". With the Tall subjects, 71.4% of the group would have preferred the screen to be tilted away from them slightly more. This could be because they were required to adopt very sub-optimal postures while 'hunching' over the computer in order to view the low screen, and by tilting the screen up slightly they would not have been required to flex the spine to a significantly greater degree than the Short and Medium subjects (see Table V, p 84 for joint angles). When the screen was raised in the two personalised workstations, all of the subjects reported the screen tilt to be "Fine".

Keyboard
The actual height of the keyboard remained constant for both the Standard and Personalised workstations. It was, however, raised slightly for some of the subjects in the Wrist Support workstation because the actual support frame raised the forearms substantially above the desk, and as a result the fingers "dropped" too far onto the keyboard. However, it was the desired effect to have the fingers "drop" marginally onto the keyboard, and this input device was therefore raised for some of these subjects. The relative height of the keyboard was altered by adjusting the height of the chair. Because the height of the keyboard was dependent on chair height, keyboard height in this

section refers to the distance between the height of the keyboard from the floor and the height of the seat pan.

The height of the keyboard was "Too high" for 12 of the 30 subjects in the Standard workstation. As Rose (1991) argued, using a keyboard that is positioned too high forces the user to elevate their shoulders thereby elevating the static load imposed upon them and increasing the level of discomfort. These perceptions of the keyboard being too high support the physiological and discomfort results obtained in this study. EMG activity in the upper trapezius was significantly higher (see Figure 32, p 96), and the incidence and intensity of physical discomfort in the shoulders was substantially greater in the Standard workstation (Table X, p 101).

When assessing the perceptions of the three subject groups to the keyboard position, it was evident that 62.5% of the Short and 40.0% of the Medium subjects reported the keyboard as being too high. This could also be associated with the 50.0% of the Short subjects who rated the chair as "Too low" in the Standard workstation. A higher chair would have enabled these subjects to reach the keyboard comfortably yet it would have been detrimental to their general seated posture. In other words, these subjects rated their perception of the chair height according to the height of the keyboard rather than to their general seated posture.

The adjustments made to chair height resulted in the relative height of the keyboard being reduced from 280mm in the Standard workstation, to a mean of 197mm in the Personalised workstation and 190mm in the Wrist Support workstation. Of all 30 subjects, 86.7% were satisfied with the adjustments made to keyboard height in the Personalised workstation. In the Wrist Support workstation, the relative height of the keyboard was not significantly different from that in the Personalised workstation. However, only 73.3% of the subjects were content with its position, and the remaining 26.7% of the subjects would have preferred a higher keyboard. Because of the dimensions of the wrist rest, no adjustment made to the height of the chair, in order to alter the relative height of the keyboard, would improved the subjects' perceptions of

keyboard height in this workstation, since the distance between the support frame and the keyboard forced the fingers and hands into an unfamiliar, yet proposed improved position while operating the keyboard.

Mouse

In both the Standard and Personalised workstations the mouse was positioned on the desk at the same height as the keyboard, and as with the keyboard, the actual height of the mouse remained the same in these two workstations, and the relative height was altered by adjusting the height of the chair. In the Wrist Support workstation the mouse was raised above the desk by a mean of 23mm thereby resulting in a vertical position of 202mm relative to the height of the chair.

While the mouse was utilised intermittently throughout the performance test, the actual mouse task only constituted 8.5% of the total performance test time. As a result, although there was no difference between the height of the keyboard and that of the mouse in the Standard and Personalised workstations, the perceptual responses to the position of the mouse were less negative than those of the keyboard. Twenty percent of the 30 subjects perceived the mouse in the Standard workstation to be too high, and the remaining 80% were content with its position. When the height of the chair was adjusted, the relative height of the mouse was reduced by a mean of 83mm in the Personalised workstation, and 78mm in the Wrist Support workstation. This adjustment resulted in 96.7% of all subjects rating the height of the mouse as "Fine", and only one of the Short subjects rating it as "Too low" in the Personalised workstation. Similar to the responses to the height of the keyboard in the Wrist Support workstation, 10.0% of the 30 subjects reported the mouse as being too low, while the remaining 90.0% of the subjects were satisfied with its position in the Wrist Support workstation. Once again the subjects were required to adopt an unfamiliar wrist posture as their right hand "dropped" onto the mouse while using the wrist support. Had the subjects been more familiar with the device, their perceptions of mouse height may have been more positively influenced.

Subjects were asked to classify the position of the mouse in terms of its horizontal position as either being "Too close", "Fine" or "Too far". Although the horizontal placement of the mouse was determined by the subjects themselves in the Standard workstation, only 56.7% of the 30 participants reported the mouse to be in a suitable position, while 23.3% of the subjects stated that it was too close to their body, and the remaining 20.0% would have preferred the mouse to be slightly closer.

All seven of the Tall subjects and none of the Short or Medium subjects rated the mouse as "Too close" in the Standard workstation, while roughly a quarter of the Short and Medium subject groups felt that the mouse was positioned too far away. Even though subjects were given the option of adjusting the position of the mouse, once they started the performance test none of them did so. As a result a number of the subjects completed the task with the mouse in a sub-optimal position.

In the two personalised workstations the mouse was positioned directly adjacent to the number pad on the right hand side of the keyboard. In the Personalised set up, 29 of the 30 subjects were content with the horizontal position of the mouse because it was located closer to the midline of the body, a factor which collaborates with several authors (Fernström and Ericson, 1997; Cook et al., 2000; Delisle et al., 2004) who argue that this limits the extent of shoulder flexion and abduction, and reduces the muscular strain imposed upon the associated musculature. With the introduction of the wrist support to the Personalised workstation, the horizontal location of the mouse remained unchanged, yet the percentage of subjects comfortable with the position of the mouse was reduced to 83.3%, and the remaining 16.7% of the 30 subjects rated the mouse as "Too far". The dimensions of the wrist support may have been slightly restrictive, and as a result of a limitation in the manufacturing, the effort required to move the right hand from the keyboard to the mouse may have been slightly increased, which could have resulted in the subjects perceiving the position of the mouse to be further away from the midline.

Table XI: Percentage of ratings of the workstation components in each of the categories for the full subject group (n=30).

	Standard			Personalised			Wrist Support		
	A (%)	B (%)	C (%)	A (%)	B (%)	C (%)	A (%)	B (%)	C (%)
Chair height	3.3	60.0	36.7	3.3	93.3	3.3	3.3	96.7	0.0
Screen height	0.0	16.7	83.3	26.7	73.3	0.0	16.7	83.3	00
Screen position	6.7	73.3	20.0	6.7	93.3	0.0	3.3	86.7	10.0
Screen tilt	30.0	70.0	0.0	0.0	100.0	0.0	0.0	100.0	0.0
Keyboard height	40.0	60.0	0.0	3.3	86.7	10.0	0.0	73.3	26.7
Mouse height	20.0	80.0	0.0	0.0	96.7	3.3	0.0	90.0	10.0
Mouse position	23.3	56.7	20.0	0.0	96.7	3.3	0.0	83.3	16.7

A = "Too high", "Too close" or "Too much towards you"
B = "Fine" (shaded area)
C = "Too low", "Too far" or "Too much away from you"

The subjects' perceptions of the workstation components correspond with the biophysical, physiological and discomfort results which demonstrate a clear improvement in the design of the workstation in the two personalised layouts. Although these workstations were considerably different to those used by the subjects on a daily basis, their perceptions indicate that the subjects recognised the benefit of implementing sound ergonomic principles.

Preference

The subjects were required to state their order of preference of the three computer workstations, taking all workstation components into consideration, and giving reasons for their choices. Of the 30 subjects, 22 of them rated the Personalised workstation as the "Best", while the remaining 8 subjects preferred the Wrist Support workstation. These 8 subjects then reported the Personalised workstation as "Second", and the Standard workstation as the least desirable. Of the 22 subjects who preferred the Personalised workstation, 15 of them stated that the Wrist Support workstation was

"Second", and the Standard workstation was "Worst", and the other 7 subjects rated the Standard workstation as second and the Wrist Support workstation as third (Figure 38).
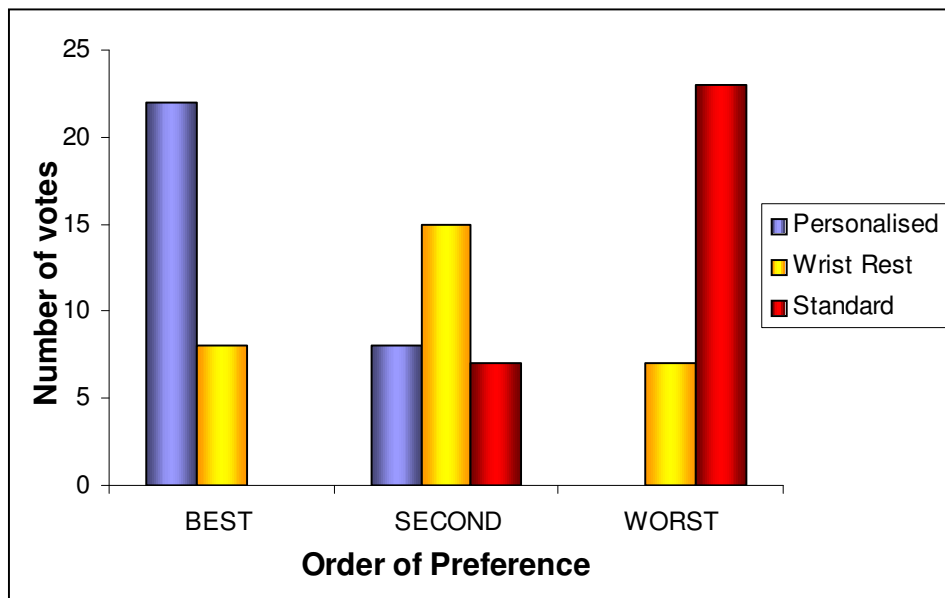

Figure 38: The order of preference of the three computer workstations.

For each vote as the "Best" condition, that workstation was awarded two points, "Second" was awarded one point, and the "Worst" workstation received zero points. The Personalised workstation received 52 points, the Wrist Support workstation 31 points, and the Standard workstation 7 points. Even with the lack of familiarity of the two personalised workstations, and in particular the Wrist Support workstation, both of these were preferred to the Standard workstation which forced the subjects into unnatural and awkward working postures resulting in elevated EMG recordings and a higher level of body discomfort.

PERFORMANCE EFFICIENCY

Pheasant (1996) proposed that increased levels of discomfort was likely to lead to distraction and as a result cause concentration to be impaired; the outcome would therefore have a negative impact on performance. In the present study performance efficiency was determined by analysing the time taken to complete the performance task and the number of errors made during testing.

Performance time and errors were independent of stature. The following results therefore address the subject group as a whole (n = 30). The data presented in Figure 39 demonstrate an improvement in the time taken to complete the performance task when adjustments were made to the Standard workstation. The Personalised workstation reflected a 4.27min reduction in testing time, while the Wrist Support resulted in a 3.00min decrease in time taken to complete the overall task compared to the Standard workstation (44.47min). The testing duration for both the Personalised and Wrist Support workstations were significantly shorter (p<0.05) than that of the Standard workstation.

As a result of the high level of variability in the number of errors obtained in each workstation, there was no significant difference between any of the workstations. However, a general trend was observed and is illustrated in Figure 39. The Wrist Support workstation resulted in the lowest number of errors (48.1 ± 18.01 SD), followed by the Personalised workstation (50.2 ± 23.31 SD) and then the Standard workstation (58.4 ± 27.89 SD).
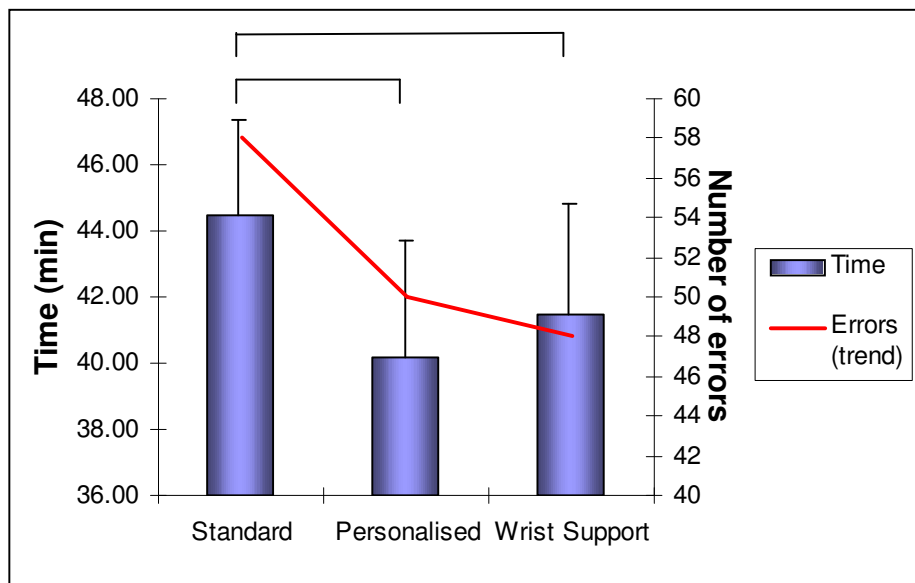
Figure 39: Overall performance results of the total subject group (n=30).
(Bars denote significant difference in the time taken to complete the performance
test at each of the workstations, p < 0.05)

In terms of the individual sub-tasks completed during the test of performance efficiency,
Figure 40 illustrates the decrease in duration for all of the sub-tasks in the Personalised
and Wrist Support workstations when compared to the Standard workstation. The editing
and numeric tasks allowed for the greatest improvement for the Personalised
workstation (1.16 min, 1.15 min reduction in duration respectively). The editing, mouse
and numeric tasks all demonstrated a similar time improvement with respect to the Wrist
Support workstation (0.73 – 0.85 min reduction in time).

When assessing the time taken to complete the performance task and the number of
errors made during the test, it is evident that the Personalised and Wrist Support
workstations allowed subjects to achieve a greater standard of performance efficiency,
which may be reflective of a decrease in the level of distraction. Blyth et al. (2003) report
that distraction is often a consequence of high levels of physical discomfort, thus an
improved computer workstation layout enables subjects to maintain a higher level of
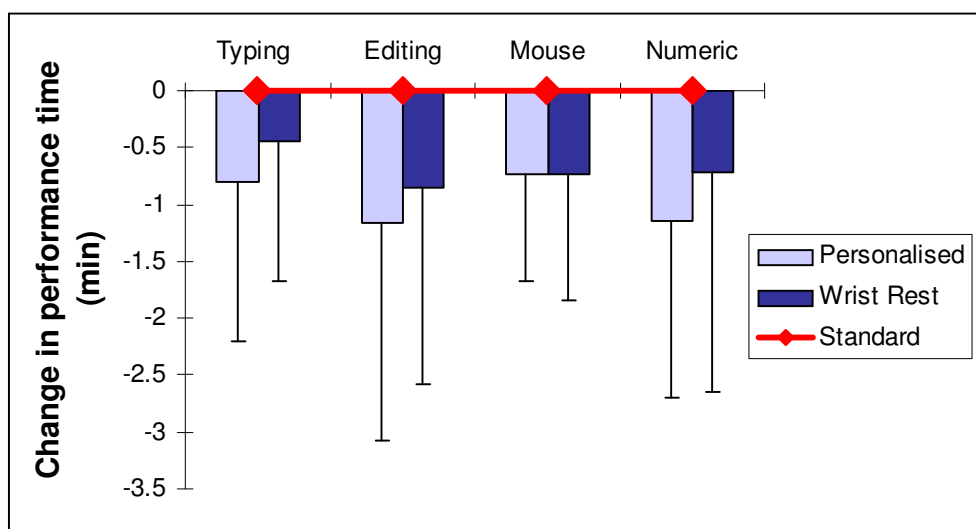concentration and enhances their performance efficiency capabilities.

Figure 40: Change in time taken by all of the subjects (n=30) to complete performance sub-tasks.

INTEGRATED DISCUSSION

While the Standard workstation imposed sub-optimal working postures and high levels of discomfort, the adjustments made to personalise this workstation resulted in numerous improvements in the subjects' responses. Previous research has reported conflicting results in terms of the ideal placement of the computer screen, and it is well documented that there is a trade-off between the preferred line of vision and the natural posture of the cervical spine (Burgess-Limerick et al., 2000; Sommerich et al., 2001; Kim et al., 2003b). In the present study the screen height was raised in the two personalised workstations, and as illustrated in Figure 41, this consequently increased the head angle thereby encouraging a more natural posture in the cervical spine.

While Ankrum (1997) suggested that a screen positioned horizontal to eye level would exacerbate visual symptoms, subjects in this study reported fewer incidences of visual discomfort (Figure 41) in the two personalised workstations where the screen was significantly raised. Furthermore, the improvement in head/neck angles, together with the positive change in general working posture resulted in a significant decrease in muscle activity of the right and left upper trapezius muscles. The mean percent MVC

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measured in the Personalised and Wrist Support workstations was 45.8% and 47.7% lower than in the Standard workstation. Ming and Zaproudina (2003) reported a high risk of neck and shoulder CTDs associated with intensive computer use. However, the reduction in trapezius load, and the decrease in the intensity and number of reports of shoulder discomfort, from 46 in the Standard workstation to 24 and 33 in the Personalised and Wrist Support workstations respectively, indicates a reduction in the potential development of a CTD. In addition, although the muscular activity of the cervical erector spinae was not measured, several studies have found a decrease in the level of activity when the screen was raised (Villanueva et al., 1997; Straker and Mekhora, 2000; Seghers et al., 2003). The 44.0% and 48.0% decrease in the number of neck discomfort reports, as well as the lower perceived intensity of discomfort in the Personalised and Wrist Support workstations, indicates a possible reduction in the muscular load imposed upon the cervical erector spinae.
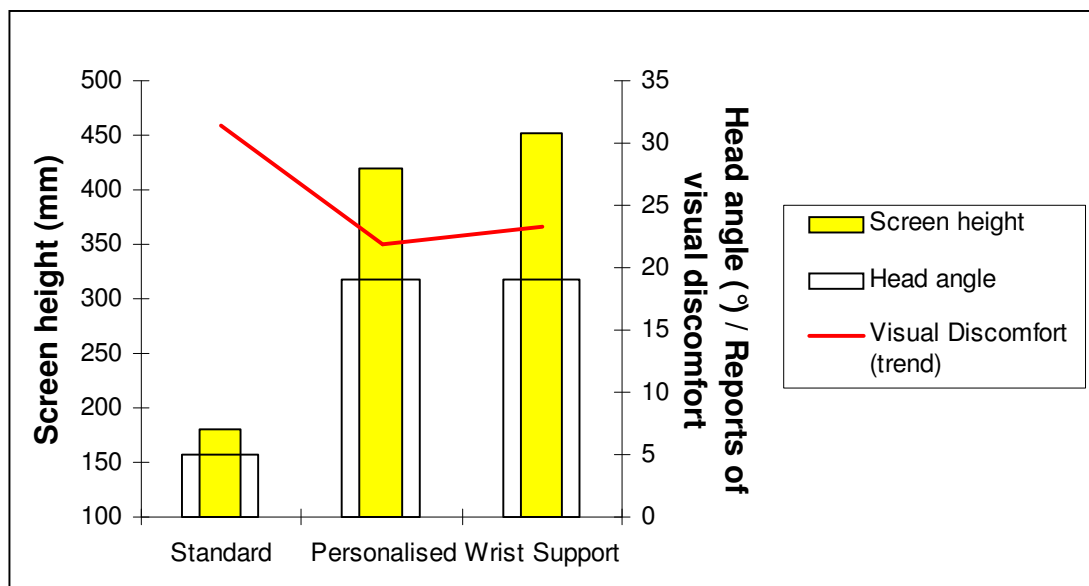

Figure 41: The effect of screen height on head angle and visual discomfort.

Due to unavoidable high levels of repetition associated with typing, together with the awkward postures forced by the use of the keyboard and mouse, the hands and wrists are prone to the development of CTDs (Amell and Kumar, 1999; Gilad and Harrel, 2000). However, Figure 42 reveals a reduction in the mean range of wrist angles in both the sagittal and frontal planes, specifically in the Wrist Support workstation.
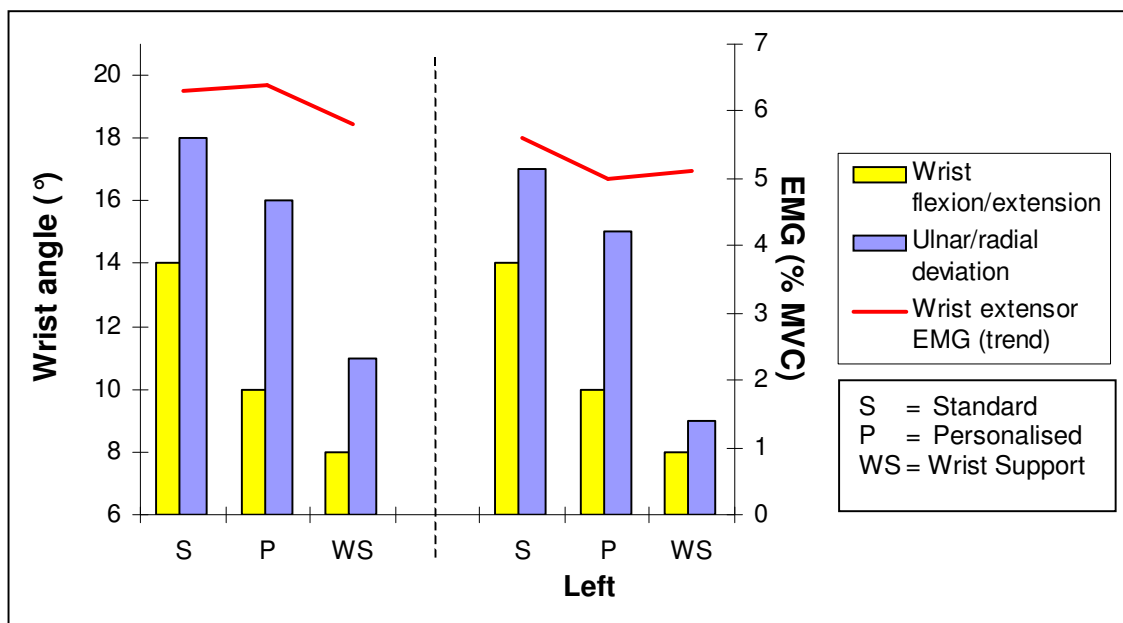

Figure 42: Wrist angles and the effect on muscle activity in the wrist extensors.

With respect to the other workstation components, the relative height of the keyboard and mouse in the two personalised workstations was lowered by raising the height of the chair. This not only allowed for more natural wrist postures in terms of flexion and extension, but it also alleviated the shoulder elevation required for subjects to operate the keyboard. Similar to the findings of Fagarasanu and Kumar (2003), the superior keyboard position therefore resulted in an additional reduction in the static load of the trapezius muscles, which was evident in the lower muscle activity levels recorded during testing. The introduction of the wrist support elevated the forearms slightly so that the fingers "dropped" onto the keyboard, allowing for a further decrease in wrist deviation in the sagittal plane. In addition the wrist support reduced radial and ulnar deviation by

mobilising the entire upper extremity when moving between different parts of the keyboard and utilising the mouse (see Figure 42).

As Sanders and McCormick (1992) pointed out, maintaining extreme wrist positions leads to inflammation of the tendons and their sheaths, which pass through the carpal tunnel, thereby elevating the pressure within the carpal tunnel. In order to assess the physiological effect of awkward wrist postures, the muscle activity of the wrist extensors was assessed. Although the degree of wrist hyperextension was significantly reduced in both personalised workstations, thereby reducing the pressure within the carpal tunnel, Figure 42 demonstrates the lack of significant difference in the muscular demand placed on the wrist extensors, since they were continuously activated in order to maintain the suspended position of the hands above the keyboard. This would also explain the high perception of discomfort in the forearms in the Wrist Support workstation. Thorn et al. (2002) noted that elevated levels of muscle activity increase the risk of developing work-related musculoskeletal disorders. While the wrist alignment and range of motion in both the sagittal and frontal planes was improved by personalising the workstation and further by introducing a wrist support, one cannot argue that the risk of developing a CTD relating to the sustained position of wrist and finger extensors was reduced. However, it is likely that the decrease in radial and ulnar deviation with the use of the wrist support would substantially reduce the CTD risk within the wrist. Furthermore, computer operators performing mainly typing tasks appear to be at the highest risk of wrist CTD development since this task was associated with the highest level of muscle activity in the wrist extensors (Figure 33, p 98).

The improvement in working postures and reduction in muscular load associated with the personalised workstations resulted in a concomitant decrease in the number of reports of body discomfort by 49.7% in the Personalised workstation and 36.9% in the Wrist Support workstation. As illustrated in Figure 43, the decrease in body discomfort was mirrored by an improvement in the subjects' perceptions of the workstation layout. The percentage of perceptions to the workstation components which were not rated as "Fine" decreased from 40.5% in the Standard workstation to 8.6% and 12.4% in the

Personalised and Wrist Support workstations respectively. The nominally worse perceptual responses for the Wrist Support workstation compared to the Personalised workstation are likely due to the lack of familiarity with any device that even marginally resembled the support frame.

Blyth et al. (2003) point out that although people experiencing work-related pain or discomfort continue to work, there is a reduction in their work effectiveness as a result of impaired concentration. Figure 43 demonstrates the performance efficiency of subjects as a product of their time taken to complete the performance test and the number of errors they made during the test. The lower levels of discomfort in the two personalised workstations enabled the subjects to perform more efficiently, as measured by a significant decrease in the time taken to complete the test at these two workstations.
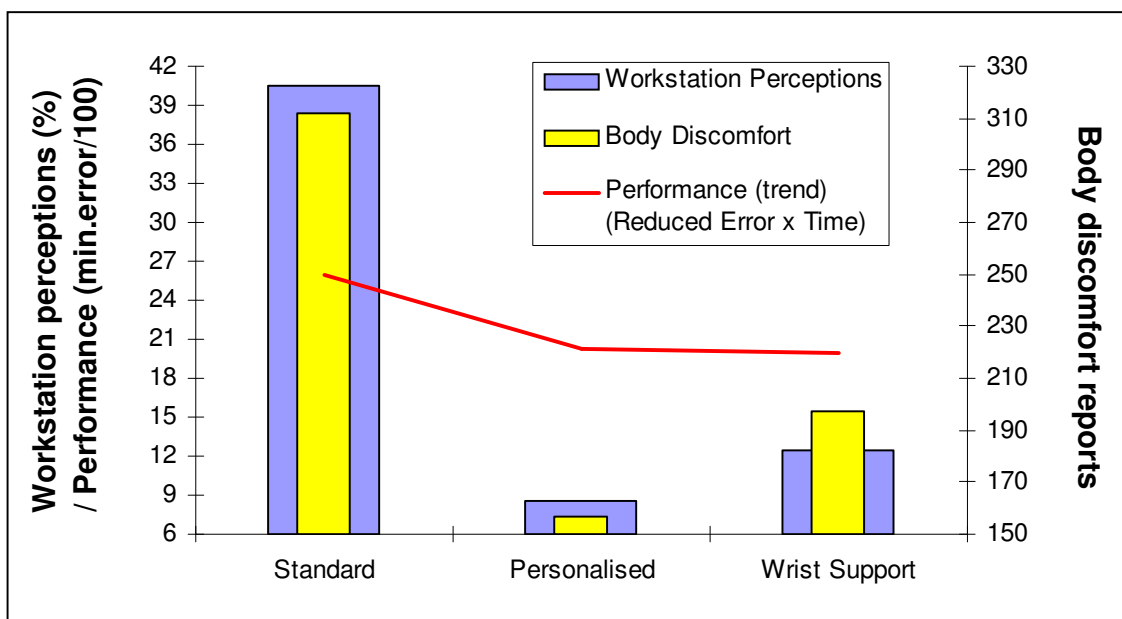
Figure 43: The effect of body discomfort on subjects' perceptions of the workstation and their performance efficiency.

The results demonstrating an improvement in the subjects' responses measured at the Personalised and Wrist Support workstations are supported by the participants' preferences of the workstations. Of the 30 subjects, 73.3% rated the Personalised workstation as the "Best" while the remaining 26.7% preferred the Wrist Support workstation. Subjects expressed that the lack of familiarity with the wrist support, and its slightly restrictive design did influence their preference for the Personalised workstation.

CHAPTER V
SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

INTRODUCTION

Human dependence on computers in everyday life has risen exponentially with the advancement of technology. With this increased automation and shift towards a paperless office, the jobs of office employees have been modified substantially. There is an increase in the static load placed on the worker as a result of diminished whole-body movements associated with the traditional office job. With this reduction in physical activity, and the increased cognitive demand of modern computer-dependent jobs, there has been a concomitant rise in the physical discomfort experienced by the employees, as well as an elevation in the number of reports of related musculoskeletal disorders (Shackle, 1991; Seghers *et al.*, 2003). The problems associated with computer workstations are exacerbated when the layout of the workstation is inflexible due to it being designed to accommodate the 'average' operator. In these instances, computer operators of extreme morphology are expected to adjust their body posture and align their body segments in unnatural positions in order to utilise the workstation.

There are several compounding factors which are responsible for the increased incidence of cumulative trauma disorders (CTDs) associated with computer use. These include malaligned and static working postures, as well as restrictive and repetitive motion of the hands and fingers. According to Mathiassen *et al.* (2003) awkward postures lead to unfavourably elevated muscle activity levels. When these unnatural postures are static and maintained for a period of time, there is continuous activation of muscle fibres resulting in a lack of recovery period, together with the overloading of muscle fibres which lead to the onset of physical discomfort and ultimately brings about the start of a muscle damaging process (Kadefors and Laubli, 2002). By monitoring the level of muscular activity with the use of EMG and assessing physical discomfort, it is possible to investigate the risks of CTD development associated with various computer workstations.

SUMMARY OF PROCEDURES

The aim of this study was to assess the effect of three computer workstations on the responses of computer operators with a wide range of anthropometric characteristics. The subject group consisted of 30 participants, all of whom were students at Rhodes University with a good level of computer experience (average of 8.2 years) and competent typing skills. The subjects spent at least 5 hours per day at a computer, with an average of 7 hours per day. In order to assess the impact of the computer workstations on operators of varied morphology, the subject group was subdivided into three stature-based groups. The subjects in the Short group had a stature of less than 1650mm, those in the Medium group were between 1650mm and 1800mm and the Tall subjects were taller than 1800mm.

The three workstations under investigation included a Standard, a Personalised and a Wrist Support workstation. The Standard workstation was set up according to the mean dimensions of three computer laboratories utilising exactly the same layout for all at Rhodes University, where the aim is to accommodate the maximum number of students regardless of the size of the individual. On the other hand, the Personalised workstation was adjusted specifically to suit each subject's morphology, and the Wrist Support workstation involved the addition of a custom-designed wrist rest to the Personalised workstation with minor adjustments made in order to accommodate the wrist support. All subjects were first tested in the Standard workstation, thereafter the two modified workstations were randomised, and testing was scheduled for the same time of day for the same subjects in order to minimise the influence of diurnal differences.

Prior to the conduction of the experimental procedures subjects were fully informed of the purpose and procedures of the study, and they were then required to read and sign a consent form. Basic demographic data and anthropometric measurements were recorded during the first testing session. In order to allow for some familiarisation to the three workstations, the subjects were required to work at the workstation for 30 minutes immediately prior to each testing session.

For the Personalised and Wrist Support workstations, the dimensions of the Standard workstation were altered significantly. The height of the chair was raised significantly for all subject groups, and although there was no difference in the chair height of the three subject groups within the Personalised and Wrist Support workstations, the shorter lower extremity length of the Short subjects was accounted for with the implementation of a footrest. The raising of the chair resulted in a decrease in the relative height of the keyboard. The height of the computer screen was also raised significantly in the two personalised set-ups. In both these workstations the screen was raised for all subjects groups; however, the adjusted screen height was significantly different for all three groups, with it being the highest for the Tall subjects.

In order to assess the effect of these workstations on the computer operator, various physical and perceptual responses were investigated. During the testing sessions subjects were required to complete a Microsoft Access based battery of tasks in order to assess their performance efficiency. Subjects were instructed to complete the performance test, which consisted of two typing sections, an editing, a mouse and a numeric section, as quickly and accurately as possible, since both time to completion and the number of errors were used to determine their performance efficiency. Video footage (10s) was taken during the first minute of each of the sections of the performance test in order to investigate the various joint angles and postures adopted at the specific workstation. EMG activity was recorded for the upper trapezius and the wrist extensors during the execution of each performance task (60s), and these data were analysed as a percentage of MVC. On completion of the entire performance test subjects were required to complete several questionnaires regarding body and visual discomfort, and their perceptions of the physical dimensions of the workstations. After participation in the final test session, subjects were required to rank the three workstations according to their personal preferences.

Basic descriptive statistics relative the variables assessed were computed, providing general information concerning the sample. Statistics were carried out on the three subject groups in order to identify stature-related differences in responses. In order to

maximise the variance in the key independent variable, stature, the data obtained for seven subjects of extreme stature in each of the Short and Tall groups, and the middle seven of the Medium group were analysed using one-way ANOVAs. In general these differences only occurred in the Standard workstation since this was designed to accommodate average operators, and the two personalised workstations were adjusted specifically to make it "optimal" for each individual thereby eliminating the differences in responses due to having to adjust the working posture when operating the computer at the Standard workstation. Therefore, when comparing the three workstations, the subject data were pooled and one-way ANOVAs were carried out on the entire sample of 30 subjects ($p<0.05$).

SUMMARY OF RESULTS

At the three workstations investigated in the present study, joint angles and muscular loads imposed by the workstations were assessed, and the subjects' perceptions of the layout, as well as their perceived ratings of body and visual discomfort, and the effect of these responses on performance efficiency were taken into consideration.

In the Standard workstation there were significant differences between the responses of Short, Medium and Tall subjects specifically in terms of joint angles. The standard dimensions of this workstation resulted in more awkward general working postures being maintained by the Medium and Tall subjects when compared to the Short subjects. The thoracic angle was a mean of 140° for the Short group which was significantly better than angles exhibited by both the Medium and Tall groups. In addition, the low screen position (180mm above the desk) forced the subjects, especially those in the Tall group, to adopt extreme neck postures. The head angle of the Tall subjects was significantly smaller than the angle measured for both the Medium and Short subject groups, and this 'stoop' posture was also reflected in a greater gaze angle for the Tall subject group. The other joint angles, including those of the wrists, indicate that the Standard workstation enforced awkward postures, which as Burgess-Limerick *et al.* (2000) point out, leads to elevated muscular demands and a high possibility of the development of a CTD.

The personalised adjustments made to the Standard workstation took each subject's anthropometric characteristics into consideration in an attempt to optimise the workstation for all subjects. These adjustments not only improved the working postures of the subjects, but they also eradicated the stature related differences in terms of joint angles. By adjusting the height of the chair and monitor, trunk angle was increased from 16° in the Standard workstation to 22° and 24° in the Personalised and Wrist Support workstations. This in turn had a ripple effect on the gaze, head and neck angles, which were also positively influenced by the change in workstation dimensions.

Adjusting the relative height of the keyboard resulted in a significant reduction of 4° in the degree of wrist extension. Because of the standard dimensions of the keyboard, ulnar and radial deviation were not influenced by the personalised adjustments. However, the introduction of the "Floating Wrist Support" in Condition 3 diminished wrist deviation in this frontal plane by 7° in the right wrist and 8° in the left wrist, and it also allowed for a further 2° reduction in wrist extension.

The more neutral joint angles in the two personalised workstations are reflected by the lower muscular demands imposed by the workstation settings. When assessing the upper trapezius muscle activity it was evident that the load imposed upon the right upper trapezius was higher that that of the left in all three workstations. However, the two personalised workstations resulted in a significant reduction in the muscular load of both the right and left upper trapezius muscles.

Although the wrist support encouraged a more neutral wrist position, wrist extensor EMG responses were not reduced in this Wrist Support workstation. A possible reason why there was no significant reduction in the wrist extensor muscle activity was because in the Wrist Support workstation the wrist extensors were activated simply to maintain the position of the hand above the keyboard. In other words, because the forearms were supported and not the hands, the wrist extensors worked against gravity to prevent the hands and fingers from "falling" onto the keyboard.

The improved working postures, together with the reduced muscular load in the upper trapezius resulted in a concomitant decrease in the occurrence and intensity of physical discomfort. The total number of reports of physical discomfort was 312 in the Standard workstation. This was reduced by 50% and 37% in the Personalised and Wrist Support workstations respectively, where the percentage of reports in the higher rating categories were also lower, thus indicating a reduction in the intensity of discomfort.

The literature is equivocal about the "ideal" placement of the computer screen due to the "trade-off" between the musculoskeletal and visual systems. In terms of visual discomfort in the two personalised workstations, where compared to the Standard workstation the screen was significantly raised, the percentage of reports of "No visual discomfort" increased 10% in the Personalised workstation and 8% in the Wrist Support workstation. Therefore, in the present study, the raised computer screen in the two personalised workstations not only resulted in an improved neck posture, but also had a positive impact on the visual system.

In conjunction with the reduction in physical and visual discomfort, the adjustments to the workstation had a positive impact on performance efficiency, which supports Pheasant (1996) who proposed that high levels of discomfort often lead to distraction and an interruption of concentration, which therefore has a negative impact on performance efficiency. In the present study there was a reduction in the time taken to complete the performance test in both the personalised workstations. The testing time was reduced by 4.27min in the Personalised workstation and by 3.00min in the Wrist Support workstation. Although there were no significant differences in the number of errors, performance in general was superior in the two personalised workstations.

The subjects' perceptions of the workstation components are reflective of the biophysical, physiological, discomfort and performance responses. In the Standard workstation 59.5% of the perceptions of the workstation components were reported as "Fine". This percentage increased to 91.4% and 87.6% in the Personalised and Wrist Support workstations thereby indicating the subjects' awareness of the improvements

made to the Standard workstation. In terms of preference, 73.3% of the subjects preferred the Personalised workstation while the remaining 26.7% preferred the Wrist Support workstation, and 73.3% of the subjects selected the Wrist Support workstation as their second preference, with the majority of them commenting positively about the concept of the "Floating Wrist Support". None of the subjects preferred the Standard workstation. The lack of familiarity with the wrist support, as well as the slight restrictive nature of the device, influenced the subjects' preferred ranking of the workstations.

HYPOTHESES

It was hypothesised that the Standard workstation would influence the responses of Short, Medium and Tall subjects differentially as a result of their diverse anthropometric characteristics and the standard dimensions of the workstation. In addition, it was proposed that the adjustments made to the Standard workstation for Conditions 2 and 3 would have a significant impact on the responses of the group as a whole.

Hypothesis 1

As the Standard workstation layout was based on the dimensions used to accommodate computer operators of "average" morphologies, the operators with extreme anthropometric characteristics were expected to be most affected by the design of the workstation. The rejection or tentative acceptance of the various categories of the first hypothesis are demonstrated in Table XII.

a) Comparisons of the biophysical responses yielded significant differences in three of the eight joint angles measured. In terms of thoracic bend, gaze angle and head angle the null hypothesis was therefore rejected. However, for the remaining body alignment responses including trunk, neck and shoulder angles, as well as wrist angles the null hypothesis was tentatively accepted.

b) There were differences in the upper trapezius EMG responses for the stature groups, therefore for the muscular activity in the trapezius the null hypothesis was rejected. However, there was no significant difference between the wrist extensor muscle

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activity recorded for the Short, Medium and Tall subjects, and the null hypothesis was therefore tentatively accepted.

c) In terms of body and visual discomfort the null hypothesis was tentatively accepted since there was no difference in the response of the three subject groups. A substantially larger percentage (69.2%) of the Medium subjects did however perceive the Standard workstation dimensions as "Fine", while both Short and Tall subjects perceived more of the Standard workstation dimensions as sub-optimal, hence when considering the perceptions of the workstation the null hypothesis was rejected.

d) The null hypothesis addressing the standard of performance was tentatively accepted since there was no difference between the subject groups in the time taken to complete the performance test or in the number of errors committed during testing at the Standard workstation.

Hypothesis 2

The Standard workstation dimensions were adjusted significantly in order to accommodate the wide variety of anthropometric characteristics amongst the subjects. The second hypothesis focused on the group as a whole and the responses they exhibited in the three different workstations. Table XIII demonstrates the rejection or tentative acceptance of the various categories of this hypothesis.

a) For the biophysical responses the null hypothesis was rejected due to the significant difference in six of the eight joint angles measured in each of the three workstations.

b) A significant reduction in upper trapezius EMG responses in the Personalised and Wrist Support workstations resulted in rejection of the null hypothesis. However, the muscle activity of the wrist extensors was not affected by the changes made to the workstation. In terms of wrist extensor EMG responses the null hypothesis was therefore tentatively accepted.

c) The null hypothesis stated that there would be no difference in the perceptual responses for the three workstations. This hypothesis was rejected due to the

substantially reduced body and visual discomfort, and the improved workstation perceptions for the Personalised and Wrist Support workstations. Furthermore, the highest preference was for the Personalised workstation, followed by the Wrist Support workstation, with the Standard workstation being the least preferred.

d) Although the number of errors made during the performance test at the three workstations was not significantly different, the time taken to complete the battery of tasks was significantly reduced in the two personalised workstations thus indicating an improved efficiency in performance, hence the rejection of the null hypothesis.

Table XII: Rejection or tentative acceptance of Hypothesis 1.

CATEGORY		Rejection of Ho	Tentative Acceptance of Ho
a	**BIOPHYSICAL**		
	Trunk angle		X
	Thoracic bend	X	
	Gaze angle	X	
	Head angle	X	
	Neck angle		X
	Shoulder angle		X
	Wrist flexion/extension		X
	Radial/ulnar deviation (Right and Left)		X
b	**PHYSIOLOGICAL**		
	Upper trapezius EMG	X	
	Wrist extensor EMG		X
c	**PERCEPTUAL**		
	Body discomfort		X
	Visual discomfort		X
	Workstation perceptions	X	
d	**PERFORMANCE EFFICIENCY**		X

Table XIII: Rejection or tentative acceptance of Hypothesis 2.

CATEGORY		Rejection of Ho	Tentative Acceptance of Ho
a	**BIOPHYSICAL**		
	Trunk angle	X	
	Thoracic bend		X
	Gaze angle	X	
	Head angle	X	
	Neck angle	X	
	Shoulder angle		X
	Wrist flexion/extension	X	
	Radial/ulnar deviation (Right and Left)	X	
b	**PHYSIOLOGICAL**		
	Upper trapezius EMG	X	
	Wrist extensor EMG		X
c	**PERCEPTUAL**		
	Body discomfort	X	
	Visual discomfort	X	
	Workstation perceptions	X	
d	**PERFORMANCE EFFICIENCY**	X	

CONCLUSIONS

The dimensions of the Standard workstation were identical for all subjects irrespective of their morphology. As this workstation was designed for operators with "average" anthropometric characteristics, Tall subjects were forced to adopt the most awkward working postures which was evident in the thoracic bend, gaze angle and head angle. These sub-optimal joint angles were generally in response to the low position of the screen, and therefore the Short subjects were able to adopt the least awkward postures

since the screen was almost at their eye-level, so the need for neck flexion or forward stooping was minimal. However, in terms of upper trapezius EMG recorded in this workstation, the Short and Tall subjects experienced the highest level of muscle activity as a result of the poorly designed workstation and the lack of adjustability to suit the workstations to their morphologies. The fact that these "mass-designed" computer workstations are designed for "average" users was supported by the subjects' perceptions of the Standard workstation dimensions. Compared to the Short and Tall subjects, a greater percentage of the Medium subject groups' perceptual reports of the workstation dimensions were ones of satisfaction.

Comparisons of the three workstations revealed that the modifications to the Standard workstation eliminated most stature-related differences and had an overall beneficial effect on the subjects' responses. These adjustments to the workstation significantly reduced the musculoskeletal stresses imposed on the various joints. The wrist angles were especially improved with the introduction of the wrist support thereby decreasing the pressure within the carpal tunnel. These improvements in working posture reduced the load placed on the associated musculature, which was demonstrated by a significant decrease in the upper trapezius EMG in both the Personalised and Wrist Support workstations. Furthermore, the two personalised workstations resulted in diminished incidence and intensity of both body and visual discomfort, and subjects' perceptions of the Personalised and Wrist Support workstation dimensions were improved in general.

The general reduction in the physical strain and perceptual discomfort recorded in the two personalised workstations was accompanied by the improved standard of performance. It is argued that the disruption in concentration, as a possible result of discomfort, was diminished when the workstation was adjusted to each subject's morphology. Although subject responses in the Wrist Support workstation were significantly improved when compared to the Standard workstation, the only further improvement on the Personalised workstation was that of the wrist angles where there was a significant reduction in the range of motion in both the sagittal and frontal planes. In terms of preference, the majority of subjects preferred the Personalised workstation,

followed by the Wrist Support workstation and lastly the Standard workstation. However, a greater familiarisation with the wrist support may have improved the subjects' measured responses as well as their perceptions of this device to which they were unaccustomed.

RECOMMENDATIONS

While the present study demonstrated clear improvements in subject responses in the Personalised and Wrist Support workstations, the data were collected on a specific target group in unfamiliar and very controlled settings. Whether these improvements would have been elicited by computer users with less developed typing skills is unclear, since the distance between the keyboard and the screen was increased substantially, and a non-touch typist may not have responded positively to such adjustments as the distance between their two main visual focus points (screen and keyboard) would also have been increased. Furthermore, the age group of the present subjects was limited to 20 – 29 years, and factors such as visual discomfort may be influenced by age. Future research could therefore take a wider range of subjects into consideration.

The environment in which testing took place was unfamiliar and the workstation dimensions of the Personalised and Wrist Support workstations may have been substantially different to those used by the subjects on a daily basis. Subjects were also very unaccustomed to the wrist support which was introduced in Condition 3. Although the subject responses improved in the two personalised workstations, further improvements may have been evident had the subjects had more time to become familiar with these workstation dimensions. It is recommended that the wrist support be used over an extended period (a week or so) rather than half an hour before testing so that the subjects would have the time and opportunity for fine adjustments to their personal needs, and become fully comfortable while using the device before the commencement of the testing session.

In addition, the wrist support was slightly restrictive as a result of a manufacturing limitation. The individual segments of the support should have flowed more freely thereby reducing the effort required to move the upper extremity while operating the keyboard and in particular the mouse. Although the width of the wrist support was adjustable, finer adjustments, especially in terms of the height of the actual support "troughs" above the keyboard, were not possible. The wrist support tested in the present study was manufactured with limited equipment by the departmental technician. Professional manufacturing of the wrist support is currently being discussed in order to improve the usability and comfort of the device, before further investigations are conducted.

In terms of assessing visual symptoms, which have been reported to be influenced by the height of the computer screen, a subjective questionnaire was used due to equipment constraints. However, with the sophisticated equipment available, a more quantitative measure of eye-blink rate, which has been identified as an indicator of visual fatigue, could be used in future research.

The final recommendation would be that adjustments should be made to the subjects' personal computers together with the implementation of a wrist support so that they can become totally accustomed to the workstation layout. A follow-up evaluation would then be useful to determine the long-term benefits of personalising their workstations and offering a form of support for the upper extremity.

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APPENDIX A: GENERAL INFORMATION

Equipment checklist

Testing protocol

Information to subjects

Subject consent form

EQUIPMENT CHECKLIST

ADMINISTRATION

Letter to subject

Subject consent form

Subject demographic and anthropometric data sheet

Performance data collection sheet

EMG data collection sheet

Body discomfort questionnaire

Workstation questionnaire

DATA COLLECTION EQUIPMENT

1 laptop with cables

Takei anthropometry set

Digital scale

2 tape measures (1 x 5m, 1 x 1m)

3 stopwatches

EMG unit and connecting leads

Razors

Alcohol swabs

AgCl electrodes

Video camera and connecting leads

Reflective stickers

Body marker pens (black and white)

TESTING PROTOCOL

Introduction

- Set up all assessment requirements
- Verbal briefing and check no metal pins or plates in upper body
- Letter of information and informed consent
- Subject demographic data
- Anthropometric measurements
- Subject must type or use internet for 30 min to habituate at each of the workstations
- Open testing programme

Electrode and marker placement

- Measure and mark wrist extensor EMG electrode placement and ground electrode placement **(Assistant)**
- Shave area
- Clean area with alcohol
- Electrode placement
- Measure and mark trapezius EMG electrode placement (subject to sit up straight for measurement of acromia) and ground electrode placement **(Assistant)**
- Shave area
- Clean area with alcohol
- Electrode placement

- Measure and mark forearm video markers **(Assistant)**
  (Right – wrist from side and above; Left – wrist from above only)
- Measure and place markers – head (corner of eye) **(Assistant)**
- Measure and place markers – back and neck (side) **(Assistant)**
  1. Head (Frankfurt place)
  2. C7
  3. T5
  4. Iliac crest
  5. Thigh
  6. Knee

- Measure and place markers – shoulders, acromia ground electrodes (behind)

Electrode attachment and MVC's

- Attach EMG electrodes **(Assistant – pass electrode leads)**

  Channels 1 and 2 – TRAPEZIUS (Plaster)

  Channels 3 and 4 – WRIST EXTENSORS (No plaster)

  Leads 1 and 3 – RIGHT (odds)

  Leads 2 and 4 – LEFT (evens)

- Obtaining "resting" (reference) and MVC data (2s each with a few seconds between) **(Assistant)**

  Left wrist extensor

  Right wrist extensor

  Right and Left Trapezius

Testing

- Subject can adjust chair, keyboard and mouse for 'personal' preference
- Run through "PERFORMANCE" test (speed and accuracy)
- Start stopwatches as subject starts the test and record time for each section **(Assistant)**

- EMG data collection
    - Typing 1 – $2^{nd}/3^{rd}$ data field
    - Editing – $2^{nd}/3^{rd}$ data field
    - Mouse – $2^{nd}/3^{rd}$ data field
    - Numeric – $2^{nd}/3^{rd}$ data field
    - Typing 2 – 3rd last data field

- Video data collection **(Assistant)**
    - A. Typing 1 – after EMG
    - B. Editing – after EMG
    - C. Mouse – after EMG
    - D. Numeric – after EMG
  - Back and neck (side)
  - Wrists (side)
  - Wrists (above)

- Digital photograph of shoulders from behind during A, B, C and D **(Assistant)**

On completion of performance test
- Questionnaires
    Discomfort
    Workstation

- Remove electrodes and markers
- Pack away
- Download

Condition 2 or 3
- Check set-up of personalised workstation
- Markers for video analysis
- Electrode placement
- Test (random)
- Questionnaires
    Discomfort
    - body
    - visual
    Workstation 2

Condition 3 or 2

- Check wrist rest position
- Markers for video analysis
- Electrode placement
- Test (random)
- Questionnaires

    Discomfort

    - body

    - visual

    Workstation 3

Department of Human Kinetics and Ergonomics
Rhodes University

INFORMATION TO SUBJECTS

Dear _____

Thank you for offering to participate in my Masters research project entitled:

The effect of personalised adjustments to computer workstations

on the efficiency and physical comfort of computer operators.

The focus of the present study is to investigate the influence of three computer workstations on various biomechanical, physiological and perceptual responses of the computer operator.

The average standard workstation such as those found in laboratories have a limited means of adjustability and are designed for operators of average morphological dimensions. Many operators using such workstations are therefore forced to adopt unnatural working postures for often prolonged periods of time. This frequently leads to discomfort, pain, loss of performance and, in the long run, musculoskeletal disorders. In order to accommodate the wide range of anthropometric characteristics, adjustability needs to be built into the design of the workstation.

You will be required to come to the Human Kinetics and Ergonomics department testing on three separate occasions. The first session will be a briefing session during which the testing protocol will be explained to you in detail. You will then be asked to sign a consent form acknowledging your willingness to participate in the study. Basic demographic and morphological data will then be collected and you will be tested at the first workstation. The following two sessions will involve testing at the two personalised workstations. In order to familiarise you with the testing environment and workstation, you will be required to work at the workstation for 30 minutes prior to testing.

I will be assessing the electrical activity in various muscles. For this electrodes will be positioned on various shoulder and forearm muscles in order to determine their muscular activity. Video analysis will also take place in order to establish the effect of the placement of the various workstation components on joint angles. Each test session will take between 45 minutes and an hour.

In order to assess performance efficiency you will be required to complete a computer task which is composed of typing, numerical, mouse and editing sections. You will be asked to complete this as fast and accurately as possible as you will be timed and the number of errors you make will be calculated.

Perceptual data (how you personally feel) will also be collected on completion of the testing. With the use of a Body Map, general discomfort will be recorded. You will be asked to rate each segment of the body on a scale of 0 (No Discomfort) to 5 (Extreme Discomfort). This will be explained further prior to testing. On completion of the final testing session you will be asked to rank the workstations according to personal preference, giving reasons for your choices. The risks involved are minimal, are of the same nature as is experienced in everyday computer use.

I will gladly give you feedback and recommendations for your personal computer workstation on completion of the study should you be interested.

Thank you for showing interest and participating in this research. Please feel free to ask me any questions.

Yours sincerely

Genevieve James
(Human Kinetics and Ergonomics Masters Student)

SUBJECT CONSENT FORM

I, _____ having been fully informed of the nature of the research entitled: **"The effect of personalised adjustments to computer workstations on the efficiency and physical comfort of computer operators"**, do hereby give my consent to act as a subject in the above named research.

I am fully aware of the procedures involved as well as the potential risks and benefits associated with my participation as explained to me verbally and in writing. In agreeing to participate in this research I waive any legal recourse against the researchers of Rhodes University, from any and all claims resulting from personal injuries sustained. This waiver shall be binding upon my heirs and personal representatives. I realise that it is necessary for me to promptly report to the researchers any signs or symptoms indicating any abnormality or distress. I am aware that I may withdraw my consent and may withdraw from participation in the research at any time. I am aware that my anonymity will be protected at all times, and agree that the information collected may be used and published for statistical or scientific purposes.

I have read the information sheet accompanying this form and understand it. Any questions that may have occurred to me have been answered to my satisfaction.

SUBJECT (OR LEGAL REPRESENTATIVE):

(Print name)	(Signed)	(Date)

PERSON ADMINISTERING INFORMED CONSENT:

(Print name)	(Signed)	(Date)

WITNESS:

(Print name)	(Signed)	(Date)

APPENDIX B: DATA COLLECTION

Subject demographic and anthropometric data sheet

Performance efficiency test

Performance data collection sheet

EMG data collection sheet

Body discomfort questionnaire

Visual discomfort assessment

Workstation questionnaire

SUBJECT DEMOGRAPHIC AND ANTHROPOMETRIC DATA
AND COMPUTER EXPERIENCE

Full name: _____   Code: _____

Date of birth: _____   (dd/mm/yyyy)

Degree: _____   Majors: _____

_____

Stature	mm
Lower limb length	mm
Popliteal height	mm
Sitting eye height	mm
Upper limb length	mm
Forearm length	mm
Shoulder breadth	mm
Mass	kg
BMI (mass/stature^2)	

1. How many years have you been using a computer on a regular basis?

   _____

2. On **average** how many hours do you spend at a computer per day?
   (Tick the appropriate box).

   0 – 4hrs   ☐

   5 – 8hrs   ☐

   9hrs +   ☐   Specify how many: _____

3. What is the **maximum** number of hours you spend at a computer in one day? (Tick the appropriate box).

0 – 4hrs ☐

5 – 8hrs ☐

9 – 12hrs ☐

13 – 15hrs ☐

16hrs + ☐   Specify how many: _____

4. On **average** how many hours do you spend at a computer per sitting (i.e. without a major break)? (Tick the appropriate box).

0 – 1hrs ☐

2 – 4hrs ☐

4 – 6hrs ☐

7hrs + ☐   Specify how many: _____

5. What is the **maximum** number of hours you spend at a computer per sitting (i.e. without a major break)? (Tick the appropriate box).

0 – 1hrs ☐

2 – 4hrs ☐

4 – 6hrs ☐

7hrs + ☐   Specify how many: _____

6. Do you take "deliberate", "mini-rest" breaks during these sittings?

☐ Yes   ☐ No

7. What is the main input device used for the type of computer work you carry out? (Tick the appropriate box).

Keyboard only ☐

Mainly keyboard, some mouse ☐

Mouse only ☐

Mainly mouse, some keyboard ☐

Other ☐

If other, please specify: _____

8. Are you able to touch type?

| Yes | Sort of | No |

9. Which is your dominant hand?

| Right | Left |

10. Do you suffer from any diagnosed computer-related musculoskeletal disorders?

| Yes | No |

If yes, specify: _____
_____

11. Do you encounter any physical (musculoskeletal) discomfort while operating the computer you use most regularly?

| Yes | No |

If yes, specify where: _____

_____

12. Do you suffer from eyestrain while working at the computer (i.e. blurred vision, dry eyes, red eyes, visual fatigue)?

| Yes | No |

13. Do you wear glasses while working at the computer?

| Yes | No |

If yes, are they bifocals?

| Yes | No |
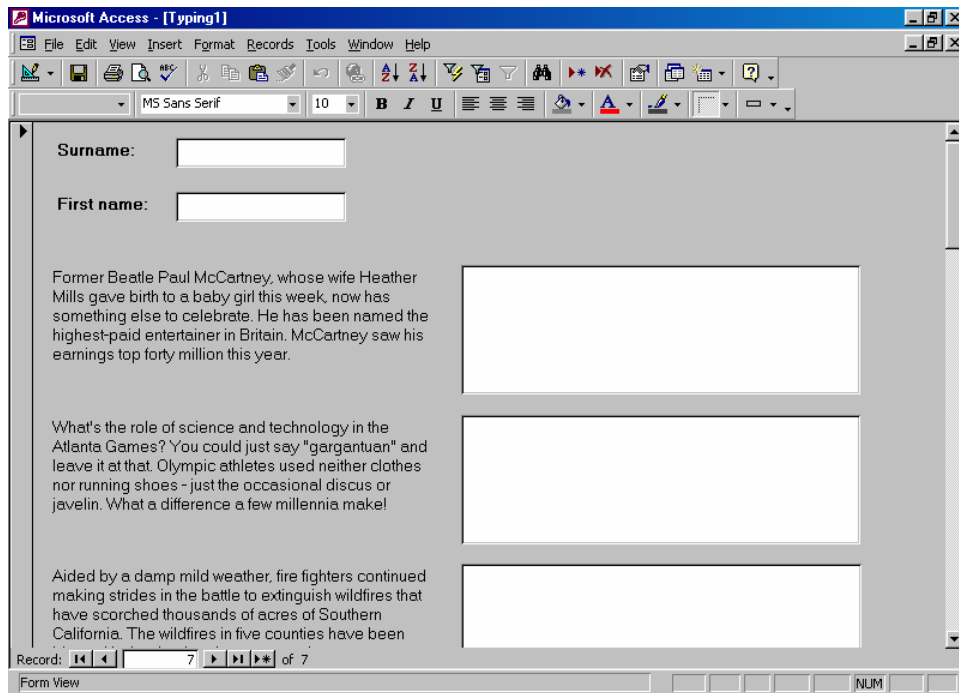
14. Do you often experience headaches while working at the computer?

| Yes | No |

15. Are there any other 'problems' you have experienced?

_____

_____

_____

_____

PERFORMANCE EFFICIENCY TEST

Typing Task

Editing Task

Mouse Task

Microsoft Access - [Mouse] window

Surname: [_____]

Choose the odd one out for each of the following:

1. [_____]
2. [_____]
3. [_____]
4. [_____]
5. [_____]
6. [_____]

How many months have 30 days? [_____]

How many weeks in a year? [_____]

Which of both of the following words are part of the body? [_____]

The weather today is: [_____]

Record: 2 of 2

Form View

Numeric Task

Microsoft Access - [Numeric] window

Surname: [_____]

```
21 39 20 52 74 80 50 72 91 78 29 33 11 80 48 74 59 88
54 59 35 14 95 90 87 12 89 65 63 61 46 18 15 39 99 83
28 47 44 90 76 55 43 59 36 42 52 12 17 12 77 63 64 14
78 97 15 30 15 29 53 51 53 79 82 40 94 78 19 62 25 41
39 22 95 68 64 69 66 92
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19 69 16 57 33 91 92 36 58 40 30 59 33 70 98 32 73 14
44 53 77 28 24 82 96 61 19 28 51 98 67 77 27 38 53 25
22 12 52 98 51 43 95 54 30 45 56 44 50 56 93 32 13 39
92 23 40 47 93 49 92 79 28 79 40 31 84 29 97 29 62 79
88 33 57 39 10 17 11 82
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84 16 38 60 88 87 61 49 85 98 50 45 60 12 65 48 34 15
22 23 76 78 66 39 25 38 24 90 88 40 30 29 54 89 92 42
38 52 83 63 75 89 66 48 61 97 12 81 45 63 24 81 96 70
80 31 87 70 75 81 72 82 70 83 12 15 77 55 61 36 70 52
64 87 49 48 71 73 46 76
```

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43 54 89 95 75 53 60 64 67 68 84 50 73 45 33 18 61 95
```

Record: 2 of 2

Form View

PERFORMANCE DATA COLLECTION SHEET

Full name: _____   Code: _____

┌───┐
│ **WORKSTATION:**   Standard (S)   Personalised (P)   Wrist Support (W) │
└───┘

Section	Time to completion (s)	No. of errors	Comments
Typing 1			
Editing			
Mouse			
Numeric			
Typing 2			
TOTAL			

EMG DATA COLLECTION

Full name: _____ Code: _____

WORKSTATION:	Standard (S)	Personalised (P)	Wrist Support (W)

EMG	Forearm extensors		Trapezius	
	Right	Left	Right	Left
Resting (baseline)				
MVC				
Marker Number				

Typing 1

	Forearm extensors		Trapezius	
	Right	Left	Right	Left
Mean				
Min				
Max				

Markers

1		5	
2		6	
3		7	
4		8	

Postural changes:

_____

_____

Comments:

_____

_____

Editing

	Forearm extensors		Trapezius	
	Right	Left	Right	Left
Mean				
Min				
Max				

Markers

1		5	
2		6	
3		7	
4		8	

Postural changes:

Comments:

Mouse

	Forearm extensors		Trapezius	
	Right	Left	Right	Left
Mean				
Min				
Max				

Markers

1		5	
2		6	
3		7	
4		8	

Postural changes:

Comments:

Numeric

	Forearm extensors		Trapezius	
	Right	Left	Right	Left
Mean				
Min				
Max				

Markers

1		5	
2		6	
3		7	
4		8	

Postural changes:

_____

_____

Comments:

_____

_____

Typing 2

	Forearm extensors		Trapezius	
	Right	Left	Right	Left
Mean				
Min				
Max				

Markers

1		5	
2		6	
3		7	
4		8	

Postural changes:

_____

_____

Comments:

_____

_____

Overall comments:

_____

_____

_____

BODY DISCOMFORT QUESTIONNAIRE

Full name: _____   Code: _____

WORKSTATION:	Standard (S)	Personalised (P)	Wrist Support (W)

Using the following body map as a guideline please indicate, by crossing the appropriate box(es), whether you experienced discomfort or not, and rate the intensity of this discomfort.
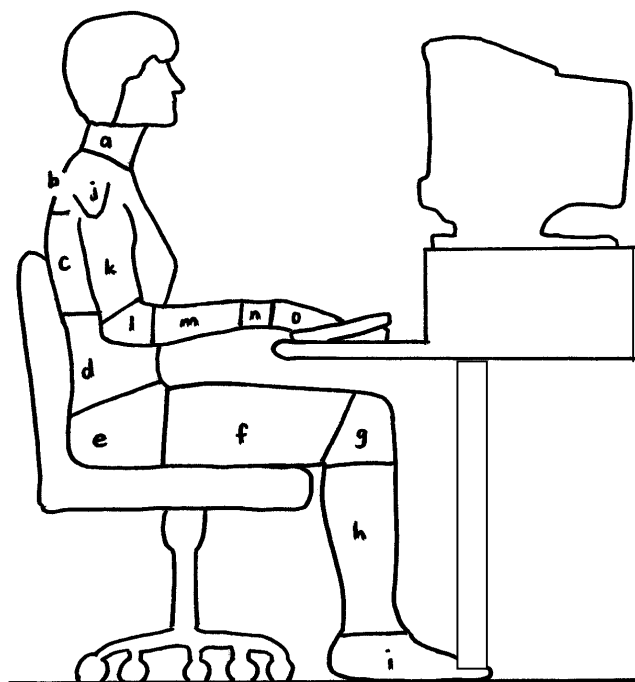
a   -   Neck
b   -   Upper back
c   -   Middle back
d   -   Lower back
e   -   Buttocks
f   -   Thigh
g   -   Knee
h   -   Lower leg
i   -   Foot
j   -   Shoulder (L/R)
k   -   Upper arm (L/R)
l   -   Elbow (L/R)
m   -   Forearm (L/R)
n   -   Wrist (L/R)
o   -   Hand/Fingers (L/R)

Neck (Segment a):

0	1	2	3	4	5
No discomfort	Mild discomfort	Moderate discomfort	Mod-High discomfort	High discomfort	Extreme discomfort

Upper back (Segment b):

0	1	2	3	4	5
No discomfort	Mild discomfort	Moderate discomfort	Mod-High discomfort	High discomfort	Extreme discomfort

Middle back (Segment c):

0	1	2	3	4	5
No discomfort	Mild discomfort	Moderate discomfort	Mod-High discomfort	High discomfort	Extreme discomfort

Lower back (Segment d):

0	1	2	3	4	5
No discomfort	Mild discomfort	Moderate discomfort	Mod-High discomfort	High discomfort	Extreme discomfort

Buttocks (Segment e):

0	1	2	3	4	5
No discomfort	Mild discomfort	Moderate discomfort	Mod-High discomfort	High discomfort	Extreme discomfort

On which side of the body did you experience this buttock discomfort?

LEFT		RIGHT		BOTH

Thigh (Segment f):

0	1	2	3	4	5
No discomfort	Mild discomfort	Moderate discomfort	Mod-High discomfort	High discomfort	Extreme discomfort

On which side of the body did you experience this thigh discomfort?

LEFT   RIGHT   BOTH

Knee (Segment g):

0	1	2	3	4	5
No discomfort	Mild discomfort	Moderate discomfort	Mod-High discomfort	High discomfort	Extreme discomfort

On which side of the body did you experience this knee discomfort?

LEFT   RIGHT   BOTH

Lower leg (Segment h):

0	1	2	3	4	5
No discomfort	Mild discomfort	Moderate discomfort	Mod-High discomfort	High discomfort	Extreme discomfort

On which side of the body did you experience this leg discomfort?

LEFT   RIGHT   BOTH

Foot (Segment i):

0	1	2	3	4	5
No discomfort	Mild discomfort	Moderate discomfort	Mod-High discomfort	High discomfort	Extreme discomfort

On which side of the body did you experience this foot discomfort?

LEFT   RIGHT   BOTH

Shoulders (Segment j):

Right shoulder

0	1	2	3	4	5
No discomfort	Mild discomfort	Moderate discomfort	Mod-High discomfort	High discomfort	Extreme discomfort

Left shoulder

0	1	2	3	4	5
No discomfort	Mild discomfort	Moderate discomfort	Mod-High discomfort	High discomfort	Extreme discomfort

Upper arm (Segment k):

Right upper arm

0	1	2	3	4	5
No discomfort	Mild discomfort	Moderate discomfort	Mod-High discomfort	High discomfort	Extreme discomfort

Left upper arm

0	1	2	3	4	5
No discomfort	Mild discomfort	Moderate discomfort	Mod-High discomfort	High discomfort	Extreme discomfort

<u>Elbow (Segment l):</u>

Right elbow

0	1	2	3	4	5
No discomfort	Mild discomfort	Moderate discomfort	Mod-High discomfort	High discomfort	Extreme discomfort

Left elbow

0	1	2	3	4	5
No discomfort	Mild discomfort	Moderate discomfort	Mod-High discomfort	High discomfort	Extreme discomfort

<u>Forearm (Segment m):</u>

Right forearm

0	1	2	3	4	5
No discomfort	Mild discomfort	Moderate discomfort	Mod-High discomfort	High discomfort	Extreme discomfort

Left forearm

0	1	2	3	4	5
No discomfort	Mild discomfort	Moderate discomfort	Mod-High discomfort	High discomfort	Extreme discomfort

<u>Wrist (Segment n):</u>

Right wrist

0	1	2	3	4	5
No discomfort	Mild discomfort	Moderate discomfort	Mod-High discomfort	High discomfort	Extreme discomfort

Left wrist

0	1	2	3	4	5
No discomfort	Mild discomfort	Moderate discomfort	Mod-High discomfort	High discomfort	Extreme discomfort

<u>Hand and fingers (Segment o):</u>

Right hand/fingers

0	1	2	3	4	5
No discomfort	Mild discomfort	Moderate discomfort	Mod-High discomfort	High discomfort	Extreme discomfort

Left hand/fingers

0	1	2	3	4	5
No discomfort	Mild discomfort	Moderate discomfort	Mod-High discomfort	High discomfort	Extreme discomfort

Please indicate the three areas in which you experienced the worst discomfort:

1   Worst

2   Second worst

3   Third worst

Neck	☐	Lower leg	☐
Upper back	☐	Shoulder	☐
Middle back	☐	Elbow	☐
Lower back	☐	Forearm	☐
Buttocks	☐	Wrist	☐
Thigh	☐	Hand/Fingers	☐
Knee	☐		

VISUAL DISCOMFORT ASSESSMENT

Did you experience any of the following visual symptoms at any stage during the testing session? (Please tick the appropriate box).

Tired eyes:	Not at all	Mild	Irritating	Excessive

Blurred vision:	Not at all	Mild	Irritating	Excessive

Dry eyes:	Not at all	Mild	Irritating	Excessive

Tearing eyes:	Not at all	Mild	Irritating	Excessive

Itching eyes:	Not at all	Mild	Irritating	Excessive

Aching eyes:	Not at all	Mild	Irritating	Excessive

Burning eyes:	Not at all	Mild	Irritating	Excessive

WORKSTATION QUESTIONNAIRE

Full name: _____   Code: _____

WORKSTATION: | Standard (S) | Personalised (P) | Wrist Support (W) |

Please tick the relevant box

1.   In terms of the chair, was it

| Too high | | Fine | | Too low |

Any specific comments _____

_____

2.   In terms of the computer screen height, was it

| Too high | | Fine | | Too low |

Any specific comments _____

_____

3.   Was the screen

| Too close | | Fine | | Too far |

Any specific comments _____

_____

4.   Was the screen tilted

| Too much towards you | | Fine | | Too much away from you |

Any specific comments _____

_____

5.   Was the position of the keyboard

| Too high | Fine | Too low |

Any specific comments _____

_____

6.   Was the keyboard angle

| Too steep | Fine | Too flat |

Any specific comments _____

_____

7.   Was the mouse

| Too high | Fine | Too low |

Any specific comments _____

_____

8.   Was the position of the mouse

| Too close | Fine | Too far |

Any specific comments _____

_____

Rank the three workstations in order of preference:

[ ] Standard workstation

[ ] Personalised workstation

[ ] Personalised workstation with Wrist Support

Why did you rank the workstations in this order?

_____

_____

_____

_____

_____

Any other comments:_____

_____

_____

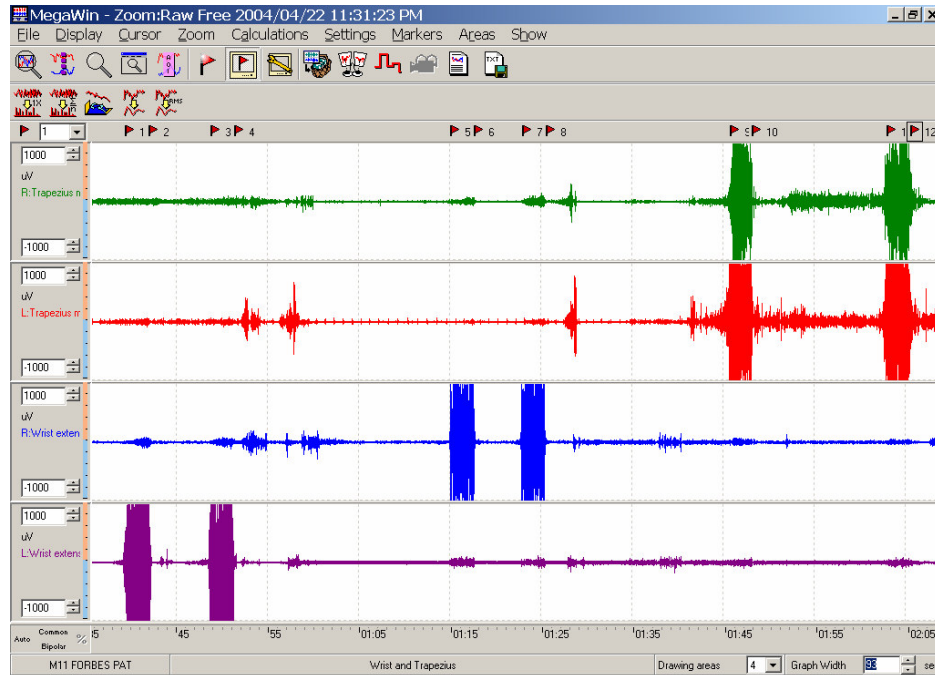_____

_____

APPENDIX C: RESULTS

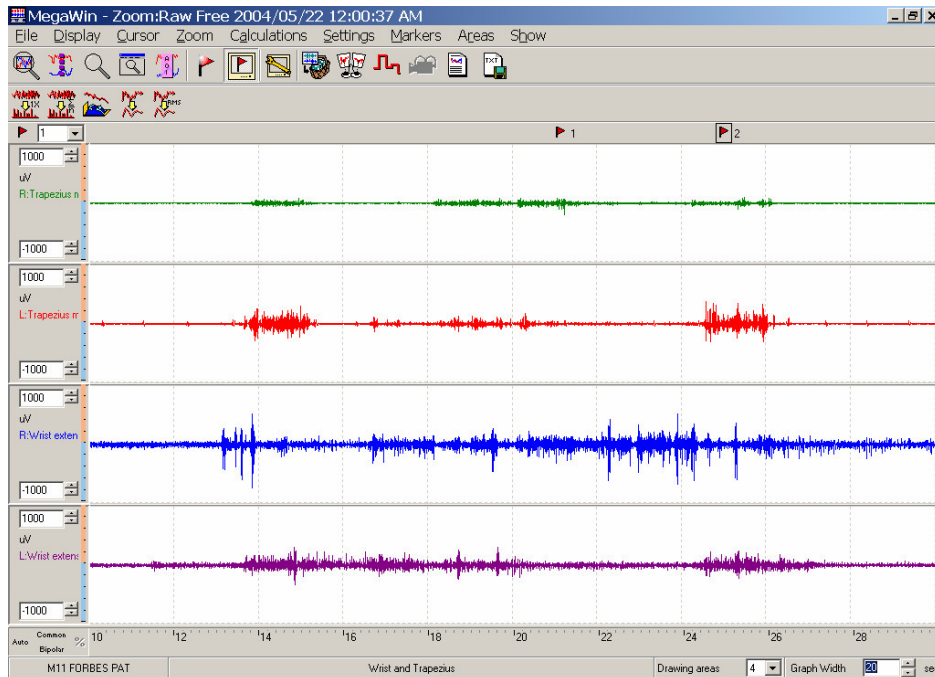EMG printouts

Statistics – descriptive statistics

Statistics – ANOVAs

EMG PRINTOUTS

Maximum Voluntary Contractions

Data Collection (20s)

STATISTICS – DESCRIPTIVE STATISTICS

	Stature	Lower Limb	Popliteal height	Sitting Eye Height	Upper Limb	Forearm	Shoulder width	Mass	BMI
Valid N	30	30	30	30	30	30	30	30	30
Mean	1732.70	896.17	406.40	799.60	760.53	476.20	429.70	74.13	24.66
Geometric mean	1729.06	893.23	401.51	797.85	758.46	474.78	427.96	72.87	24.37
Median	1735.00	899.50	414.00	799.00	756.50	472.50	427.00	73.10	23.97
Mode	1714.00	889.00	Multiple	Multiple	Multiple	452.0000	Multiple	Multiple	Multiple
Minimum	1476.00	734.00	172.00	684.00	634.00	399.00	343.00	47.50	18.69
Maximum	1964.00	1031.00	464.00	921.00	863.00	538.00	494.00	109.00	34.75
Lower quartile	1650.00	862.00	394.00	766.00	721.00	452.00	398.00	66.60	21.90
Upper quartile	1779.00	944.00	436.00	832.00	803.00	504.00	458.00	85.00	26.50
Range	488.00	297.00	292.00	237.00	229.00	139.00	151.00	61.50	16.06
Quartile range	129.00	82.00	42.00	66.00	82.00	52.00	60.00	18.40	4.60
Variance	12935.87	5307.45	2810.66	2913.42	3228.88	1377.96	1542.77	194.08	15.47
Std.Dev.	113.74	72.85	53.02	53.98	56.82	37.12	39.28	13.93	3.93
Standard Error	20.77	13.30	9.68	9.85	10.37	6.78	7.17	2.54	0.72
Skewness	-0.08	-0.38	-3.14	0.33	-0.10	-0.15	0.05	0.35	0.83
Std.Err. skewness	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43
Kurtosis	0.10	-0.22	13.19	0.34	-0.32	-0.62	-0.53	0.26	0.45
Std.Err. Kurtosis	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83

STATISTICS – ANOVAs

ANOVA table showing anthropometric characteristics for the three subject groups.

	SS Model	df Model	MS Model	SS Residual	df Residual	MS Residual	F-ratio	Sig. Level
Stature	312323.143	2	156161.571	43385.143	18	2410.286	64.78965	0.000000
Lower Limb Length	92042.000	2	46021.000	45172.571	18	2509.587	18.33807	0.000045
Popliteal Height	17926.952	2	8963.476	5484.857	18	304.714	29.41600	0.000002
Sitting Eye Height	56208.286	2	28104.143	19068.000	18	1059.333	26.53003	0.000004
Upper Limb Length	56932.952	2	28466.476	25548.857	18	1419.381	20.05556	0.000026
Forearm Length	30986.000	2	15493.000	4634.286	18	257.460	60.17626	0.000000
Shoulder Width	15237.810	2	7618.905	19213.429	18	1067.413	7.13773	0.005219
Mass	1099.601	2	549.800	2097.111	18	116.506	4.71907	0.022504
BMI	45.634	2	22.817	206.773	18	11.487	1.98628	0.166160