Video display terminals an ergonomic evaluation of workstations and operating postures.

Sandra Gail. Chisvin

University of Windsor

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VIDEO DISPLAY TERMINALS:
AN ERGONOMIC EVALUATION OF WORKSTATIONS
AND OPERATING POSTURES

by
Sandra Gail Chisvin

A Thesis
submitted to the Faculty of Graduate Studies
through the Department of
Human Kinetics in Partial Fulfillment
of the requirements for the Degree
of Master of Human Kinetics at
The University of Windsor

Windsor, Ontario, Canada
1983
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ABSTRACT

VIDEO DISPLAY TERMINALS:
AN ERGONOMIC EVALUATION OF WORKSTATIONS
AND OPERATING POSTURES

by

Sandra Gail Chisvin

This paper presents, in the form of a field study, an ergonomic evaluation of a sample of VDT workstations and female operators. 21 individual stations and operators were examined via direct observations, physical measurement techniques used on location, and photographic data collection. Two kinds of hardware were employed at the workstations - 7 "Micom" stations and 14 "Wang" stations were studied.

The results of a questionnaire previously distributed by Ontario Hydro's Health and Safety Division, (in which questions pertaining to the use of VDTs were included), were also consulted and evaluated. This survey provided information concerning the rate of reporting of physical complaints among VDT users and non-users, and the specific symptoms experienced.

The work stations require that an operator work in constrained working postures; due to the nature of both the hardware involved and the tasks performed. The constraints are, therefore, environmentally imposed. Of particular interest were the user preferences for adjusting the workstation components, and the ways in which these preferences compared to literature recommendations for workstation configurations, (for female operators only).
Medical and ergonomic studies have demonstrated that 'poor' posture is often accompanied by pains in muscles and tendons, joints and ligaments. Intradiscal pressures of the vertebral column have also been shown to rise to potentially harmful levels.

Recommendations have been made concerning the improvement of the investigated workstations, and a prototype workstation has been introduced for future consideration.
ACKNOWLEDGEMENTS

I would like to thank Ontario Hydro for providing me with subjects and a true-to-life laboratory with which to work. I would also like to thank my committee members for their guidance and assistance during this project. And finally, thanks go to my family, and especially to Mark, for seeing me through this with patience and encouragement.
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Review of Literature

The video display terminal is a relatively new piece of office equipment; one which is rapidly proving to be a necessary and integral part of standard office furnishings. The work habits associated with the terminal have introduced a wide variety of new and unique problems to the work environment, commonly involving employee discomfort and dissatisfaction (Galitz, 1980; Grandjean, 1982a; Wright, 1982).

Since the evolution of ergonomics as it is known today, (around WW II), researchers have devoted considerable time and effort to the problems of workstation design. In more recent years, much attention has been focused on the specific situation of visual displays and CRTs (cathode ray tubes), especially with the introduction of computers and display screens into the work setting.

The arrival of VDTs in the work place has made health and safety a major preoccupation amongst those who must work with the terminals. Such a torrent of health complaints has never been created by anything else in the office (Makower, 1981).

A job should be treated as a lifetime activity. We must appreciate that the time spent at work represents approximately one third of an adult's working life, equaling thousands of hours. It is important, therefore, that the working environment be as conducive to healthy and comfortable habits as possible. Corlett and Manenica (1980) have shown that years of working in a strenuous setting can exert upon an individual rather severe detrimental and often permanent effects, (bodily distortion, chronic pain and fatigue, loss of full range of motion of affected joints).

It is not sufficient to simply place a screen and keyboard wherever desk space can be found; several issues must be given consideration. Who
will be using the terminal? What functions will the terminal serve? How long will an operator be required to use it? To merely suggest total adjustability as adequate ergonomic consideration does not answer the question of who will be accommodated by the adjustments.

A good workstation design depends on the proper arrangement of individual parts so that they will work well together, and with the user (Galitz, 1980). A poor design will lead to fatigue and cumulative discomfort, with impaired performance. Thus, the comfort and well-being of an operator may be determined, to a certain extent, by the degree of adjustability of the equipment (Ayoub, 1973). However, there must be more to a good design than simply using adjustable components, or the major problems existing today would, for the most part, already have been solved.

In reality, the success of any attempt to encourage a favourable working posture when using VDTs depends very much upon the attributes of the individuals concerned. It is wrong to presume that the behavior of an operator can be suitably altered by simply making a series of (appropriate) recommendations as to what should be done (Cakir et al., 1980). In general, an individual tends to assume a position which is suitable for the short term optimization of the way in which the work is performed, giving little or no thought to the possibility of longer term effects, such as fatigue. The long term consequences of poor posture, especially the possibility of irreversible postural damage, are seldom considered (Cakir et al., 1980; Kroemer & Price, 1982).

Fatigue may be experienced as various symptoms of discomfort or strain of the eyes, neck, back, arms and other body parts; the muscular overloading syndrome is largely responsible here. However, these
complaints cannot be entirely dissociated from the psychological reactions of the individual to his/her role. This merely makes the whole issue of workplace improvement that much more complicated and involved (Makower, 1981).

The likelihood that a VDT operator will experience fatigue or stress at work is controlled to a large degree by his/her sitting position (Wright, 1982). But one must also be aware of the fact that while fatigue, (due to VDT use), may arise from physical problems associated with inadequate workplace design and the subsequent posture, it may also arise from any combination of several other factors.

What, in fact, is posture? According to Lavelle (1982), it is the organization of bodily segments in space according to the force of gravity. It depends on the characteristics of the task and the conditions under which performance occurs. Posture is governed by the intrinsic conditions of man at work as well as by external constraints linked to the execution of the task at hand.

Corlett (1982) has recognized posture as being the result of workplace design. Furthermore, he has stated that we must design for the postural needs and against a specification. In this instance, a specification presupposes the existence of criteria against which requirements are selected.

Postural efforts involve the static muscle contractions concerned, during which they remain in a state of heightened tension with the forces exerted over an extended period of time. In the event that the work is not physically demanding, (in a gross motor activity sense), as in the operation of a visual display terminal, then the pain arising from the muscles used, to maintain the working posture could be the factor deciding whether or not the work will continue.
Çakir et al. (1980) concluded from their research that even the most ergonomically sound postures will become fatiguing after a period of time, due to an excessively high level of static muscular loading. Man is designed to move; any posture can have negative effects if maintained for too long.

In studies such as those by Duncan and Ferguson (1974) and Hunting et al. (1981), numerous problems and complaints associated with posture were revealed, occasionally among conventional office workers and particularly among VDT users. The long list of complaints includes: stiff and soreness of the neck and shoulders; backaches; fatigue, (localized and general); pressure points; numbness of the extremities; loss of strength in the hands and arms; swollen joints; and assorted visual problems. Similar reports were made by the authors of virtually all of the major studies found in the literature. Time and again, the same difficulties are seen to arise (Van Wely, 1970; Corlett & Manenica, 1980).

After examining the literature to date, it becomes rather obvious that the research has not really advanced in terms of improving the comfort and well-being of VDT operators for twenty or thirty years. The same problems still persist. Considering the number of years man has devoted to designing chairs, (over 2,000 years), the construction of seating for maximum health and comfort still evades the designer (Wallersteiner, 1982).

The crux of the problem of designing the best possible VDT station for the most users seems to stem from the role of the chair, first and foremost. One applicable definition of task seating is a product designed to meet any seated function where the user, in order to work
and perform effectively, is required to maintain a fixed position for periods that could exceed one hour (Hockenberry, 1982).

It is ironic that, historically, the evolution of seating has been inspired by the desire to make man more comfortable. This attempt has been made in an effort to reduce the physical strains on the body and hopefully, induce relaxation. Yet it appears that the seated position, which has now become more or less second nature to modern man and the most frequently assumed, is one of the most potentially harmful body configurations (Makower, 1981). Sitting fixtures have found their niche as one of the most important furnishings in the modern world. They dictate the postures we assume both at work and at leisure.

When an individual assumes various sitting postures, the configuration of the spine undergoes corresponding changes. Figure 1 illustrates some of these differences. Compared to the standing position, adopting a relaxed sitting pose, (without external support), increases the load on the lumbar spine. A kyphotic spine (convex) replaces the natural lumbar lordosis, normally concave, as shown in B. As a result, a longer moment arm is created, which increases the torque, or moment of force exerted by the weight of the upper body on the lower back. Since \( \text{MF} = \text{FxFa} \), where \( \text{Fa} \) is the moment arm, (or force arm), it follows that when the value for \( \text{Fa} \) increases, so must \( \text{MF} \). In other words, torque (MF) represents the effect of a force acting on a body (or body part) as the force is exerted a specific given distance away from the axis of rotation. When the force arm increases, there exists, in turn, a greater moment of resistance, and the receiving body must apply a larger counterforce if equilibrium is to be established and/or maintained (in accordance with the conditions of equilibrium).
Figure 1. Changes in spinal configuration with postural changes. When standing erect (A), the natural lordosis is maintained. Sitting in a relaxed position shifts the line of gravity ventrally (B). There is a backward pelvic tilt, and a longer force arm (Fa). Intradiscal and intervertebral pressures increase. When sitting upright (C), the pelvic tilt shifts forward. The force arm is shorter than for relaxed sitting, but is still longer than for standing.
In this instance the applied force is the weight of the upper body and torso, acting downward (due to gravity) on the lumbar vertebrae. The counterforce is, therefore, that exerted by the postural muscles in order to hold the body in the upright position. Hence, it is desirable to shorten the moment (or force) arm.

An upright sitting posture helps reduce the kyphosis somewhat, returning the moment arm to a shorter length once again. But it still exceeds the moment arm when standing. A common occurrence is the over-accentuation of the natural spinal curves when sitting erect. As the forward pelvic tilt becomes over-emphasized, the stresses on the spine, (compressive), begin to increase again. This can be as potentially harmful as sitting without any support.

It is not only the lumbar vertebrae which are stressed when sitting. Tichauer (1973, 1978) has shown that leaning forward from the neck can place considerable undue strain on the cervical portion of the spine. In fact, an erect head can reduce the compressive stress between the sixth and seventh vertebrae by as much as three times.

Deliberate attention must be given to the placement of the workstation components with respect to the totality of the work environment, in order to achieve a multi-user, effective, healthy and satisfying working office having maximum efficiency. With the advent of job rotation, and sharing of VDTs by a multiplicity of users, it has become essential to include in a workstation multi-user capabilities (Wallersteiner, 1982).

Part of the difficulty in trying to create the ideal workstation lies in the inconvenient truth that there is no such creature as an average person. Workplace dimensions should be preferably compatible with the anthropometric characteristics and limits of the anticipated
user population.

At work, the most important workplace design requirements follow as a direct result of skeletal and muscular structure of the body and its "affinity for movement and the need to minimize static strain (Cakir et. al., 1980). This becomes nearly impossible when upwards of 150 possible human dimensions can theoretically be involved.

As recently as this year (1983) Grandjean has acknowledged the inconsistencies between the preferred body postures, and workplace settings chosen by subjects as compared to the textbook and literature suggestions. Yet still it is maintained that the adjustable VDT workstations can substantially contribute to comfortable and suitable working postures. Surely it cannot be that simple — the notion of adjustability was taken as gospel as long ago as the 1950's, and preached endlessly ever since. There is obviously more to a practical solution than that (Floyd & Roberts, 1958).

Almost every author who has conducted research in this area has provided numerical data pertaining to the physical set up of a VDT workstation. The ranges of these values, (seen in Appendix C), are so large that one might wonder where the numbers ever came from in the first place.

Extrapolating the results of studies which were made within specific occupational groups or laboratory subjects to other groups with different types of needs and activities can be misleading (Cakir et. al., 1980). Every situation is unlike any other.

Generalizations are useful in the initial determination of how a workstation may best be arranged. Following this stage, however, they are of little assistance. The designer or engineer requires detailed
knowledge of the specific functions the workstation is to fulfill before establishing the more precise configuration characteristics crucial to healthful and efficient operation. Perhaps the answer could lie not so much in the improvement of existing designs, but a re-evaluation and recreation of the entire VDT workstation concept.

Ontario Hydro has a vested interest in such research, primarily because there are presently hundreds of terminals in use throughout the company, and more are being introduced at a very rapid rate. Several incidents reported in the media in recent months have generated a number of concerns and fears among the employees who are required to operate VDTs.

Employees have expressed concerns regarding not only the possibility of radiation hazards, but also their general health and well-being, in terms of the possible effects of working at confined stations all day long. The press has devoted a great deal of attention to the possible physical dangers an operator might face, and the vast array of unfavourable consequences that could be experienced.

As a result, this thesis attempts to offer some suggestions as to how the workstations may be improved from a user-comfort and satisfaction point-of-view, and some new ideas for consideration in the design of future VDT workstations suitable for a variety of users.
Statement of the Problem

In light of Ontario Hydro's needs, as well as in an effort to suggest new ways in which a VDT workstation might be constructed, this study sets out to fulfill four major goals:

1. To record and evaluate the characteristics of a sample of VDT workstations at Ontario Hydro, and the postures adopted by the operators.

2. To compare the findings at Ontario Hydro with the most 'ergonomically sound' guidelines found in the literature, (resorting primarily to the recommendations of Cakir et. al., 1980, and the various publications by Grandjean).

3. To suggest ways in which the stations at Ontario Hydro might be improved, using their existing facilities; i.e., short term, temporary measures that can be taken.

4. To generate new design possibilities for such working environments, based upon the availability and limitations of the hardware on the market, and the anthropometric features of the anticipated user population.
Methods and Procedures

An investigation of this sort, namely an ergonomic field study, requires that certain elements of the protocol differ from the traditional laboratory investigation procedures. However, a field study has the advantage of possessing a greater degree of realism than does a typical experiment conducted in an artificial environment. In order to collect the relevant data needed to fulfill the objectives of this research, several data collection methods have been employed. This sort of multi-mode approach is not unlike that of Cakir et al. (1980), Stammerjohn et al. (1981), Stewart (1982), and many others.

Subjects

The total subject pool was initially comprised of the total clerical population at Ontario Hydro, 95% of whom are women. From this group, the survey portion was conducted among 1,918, of which 1,166 returned completed and useable questionnaires. The remainder of the study was performed with the cooperation of 27 volunteers from one particular location. The volunteers were randomly selected, based on the order of return of signed consent forms. The final subject count after the collection of data was reduced to 21, due to the inability to extract certain data from the slides which were required for further analysis. Subjects ranged in age from approximately 20 to 50 years.

The two groups of subjects served different purposes. The questionnaire group essentially provided subjective and qualitative information regarding the physical effects experienced by VDT operators, using similar equipment to the other 21 subjects. On a much smaller scale, the group of 21 provided more specific quantitative data concerning actual physical workstation dimensions and exact postural
configurations. They provided the fundamental data upon which the biomechanical analysis was based.

Data Collection and Analysis

The Safety Services Department of Ontario Hydro recently conducted a survey among 1,918 of its clerical employees, pertaining to attitudes and perceptions regarding their work climate, VDT use, and general job satisfaction. Ratings on 12 physical symptoms and several covariates, (i.e., job strain, satisfaction, etc.), were compared for VDT users and non-users.

In order to reduce the rather 'emotional' nature of the issue of VDTs, the survey questions of particular relevance to VDT use were embedded within other questions of a survey already publicized, pertaining to clerical employees and their occupations. Participation was strictly on a voluntary and anonymous basis. The specific questions of interest to this study are indicated in Appendix F.

Direct observations were made at each of the workstations while the operators were at work. Two particular models of hardware were involved: Micom units and Wang units. Observations included the completion of a qualitative evaluation checklist, (see Appendix A), dealing with the physical configuration of the workstation and the general postural features of the operators. In addition, any other observations of interest were noted.

The next phase of data collection was the taking of direct measurements. Using simple tools, (tape measure, protractor, and carpenter's level), a number of dimensions were measured from the workstations. These values were recorded primarily as a standard against which the accuracy of the photographic scales and values could
be compared. A light meter was also used to record illuminance at each station. (Illuminance is the amount of light striking a surface, which may then be either reflected or absorbed.) The units of measure were footcandles (fc) and lux (lx). One footcandle represents the rate of emission of light from a source per square foot. Similarly, one lux is equivalent to the rate of light emission per square meter. One fc is approximately equal to 10 lx. Thus, illuminance is actually a measure of light per unit area.

The gathering of photographic data comprised the major portion of the data collecting activities at the Ontario Hydro work sites. A tripod-mounted Minolta SRT 201, (35mm, semi-automatic, SLR), camera was used to photograph the VDT operators in their 'natural' working environment. Kodak EL 135, reversible, colour slide film was used at ASA 400. Prior to being photographed, each subject was observed for a time to ensure that the postures being captured on film were truly indicative of the most typical working positions.

Whenever possible, the camera was set up at a right angle to the operator, in order to obtain lateral views for the quantitative analysis. A fixed item in the plane of motion was measured directly at each individual station so that scale factors could later be established. As it was not possible to set up the camera at an equal distance from every station, each slide has its own scale factor.

All photographs were taken between the hours of 1 p.m. and 3 p.m. over a period of 5 consecutive days. Re-takes were collected to confirm consistency of the postures recorded.

The slides were analyzed using a numonics graphics calculator to locate the body segments and workstation components in space, relative
to each other. The slides were projected through a standard carousel projector, which was suspended over a slanted work table, (on which the projected image was observed). Geometric and trigonometric principles were then used to complete the biomechanical analysis of the operating postures.

Digitizer values were measured several times to ensure the consistency and accuracy of the data measurements. For the analysis, the body was treated as a link-segment model consisting of 8 links and 7 joints. The body was considered from the lateral plane only, as illustrated on the diagram in Figure 2.

The emphasis for the analysis has been placed on the upper body, (torso and arms), since these are the body parts which appear to be most greatly affected, according to the reports found extensively throughout the literature, (as well as indicated in the questionnaire results).

Upon completion of the data collection and analysis, the results were considered in conjunction with standard anthropometric data for females and the current literature, to make recommendations as to how the Ontario Hydro stations might be improved upon. In addition, a new workstation design has been presented for future consideration; a design which could possibly alleviate some of the more prominent and severe postural and physical problems that the existing stations create and/or contribute to.
Figure 2. Link segment model. The body has been divided into 8 links, or segments, joined at 7 joints. A stick figure has been superimposed on an enfleshed diagram. The links include the head and neck, trunk, thigh, shank, foot, upper arm, forearm, and hand. The corresponding joints include the neck, hip, knee, ankle, shoulder, elbow and wrist.
Results

Survey

This survey was conducted in an effort to discover whether or not VDT operators suffered from and reported a greater incidence of physical discomfort, as compared to other clerical employees; and if so, what symptoms are experienced and with what might they be associated? A return of 1,166 questionnaires from 1,918 (61%) were received. (The total population of Ontario Hydro clerical employees numbers roughly 4,300.)

Four specific groups were polled:

i) no office equipment used (14%)  
ii) clerical equipment only (i.e., standard office items) (27%)  
iii) VDT equipment only (21%)  
iv) mixed - clerical and VDT equipment (38%)

Thus, 59% of those polled used VDT equipment either exclusively or in conjunction with other office tools.

Initially, it was found that five physical symptoms and four covariates were significantly related to VDT use. Other less significant variables were also somewhat associated with the operation of VDTs, (soreness of arms, aches in back, legs, and general body fatigue). The significant symptoms included eye strain, blurred vision, headaches, sore fingers, and aches and soreness of the neck and shoulder regions. Further analysis of these five symptoms, while controlling for the influence of the covariates, revealed a definite, significant relationship for three symptoms in particular, of which the discomfort of the neck and shoulders was one. The others included eyestrain and blurred vision. The portion of each population experiencing these three problems was as follows:

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<th>Condition</th>
<th>Equipment</th>
<th>Clerical</th>
<th>VDT</th>
<th>Mixed</th>
<th>Total Sample</th>
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<tr>
<td>eye strain</td>
<td>23%</td>
<td>18%</td>
<td>34%</td>
<td>32%</td>
<td>29%</td>
</tr>
<tr>
<td>blurred vision</td>
<td>7</td>
<td>5</td>
<td>16</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>aches in neck &amp; shoulders</td>
<td>11</td>
<td>17</td>
<td>19</td>
<td>23</td>
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Note the similar relationships for the VDT and mixed groups when contrasted with the no-equipment and clerical groups. (Tests of significance were made with a multivariate analysis of variance, which uses means, standard deviations and intercorrelations.)

There is clearly a slight increase in the incidence of said complaints when VDTs are introduced into the working environment, as evidenced by these results. Nothing more specific can be said at this time; a further and more in-depth study is required if greater detail of results is desired.

There are two major conclusions that can be drawn from this survey:

1. VDT operators report a high incidence of physical discomfort.
2. Aches and soreness in the neck and shoulders are significantly frequent complaints, deserving of attention; i.e., worthy of investigating why this is so and what can be done about it.

Because of the results of this questionnaire and the strong emphasis in the literature, the biomechanical evaluation has been restricted primarily to the confines of the upper body and limbs. These are the areas of the body around which the most frequent and serious problems appear to revolve.

**Qualitative Data and Direct Observations**

The completion of the checklist, (as described previously and seen in appendices A and B), has revealed that all operators and workstations
demonstrated certain common features. The leg areas under the desks were free from obstruction and provided sufficient clearance; all components, (screen, keyboard, source document holders), were detached and easily rearranged; the chairs were fully adjustable and equipped with moveable backrests; adjustment mechanisms were protected and secure from inadvertant or accidental release; no station had a footrest of any sort; all operators maintained relatively horizontal thighs; a minimum of fidgeting was observed.

Other observations were not relevant to all 21 operators inclusively. Only eight demonstrated vertical legs, and in only six cases were the feet resting flat on the floor. All but two had their legs crossed one way or another, (at the thighs, knees, or ankles). Seven of these women also had their feet wrapped around the bases of the chairs. Most had their heads held upright or inclined forward, while few were leaning back from the neck, (with respect to the vertical plane). The trunk position in nine operators was behind the vertical plane. Forward curvatures, or arches, of the spine were demonstrated in almost 50% of those observed. Fourteen were working with near-vertical upper arms while twelve maintained a horizontal position of the lower arm.

Overall, only four subjects demonstrated what can technically be considered an ergonomically sound and correct posture. The typical optimal sitting posture has been most often described as meeting the following criteria:

- thighs and forearms approximately horizontal
- upper arms and lower legs approximately vertical
- feet resting flat on footrest (or floor)
- head held upright, or with a forward inclination of
no more than 30° from the vertical.

And, as often noted in much of the literature, even this best of postures is not infallible in resisting the onset of physical discomfort and irritability. The checklist responses are summarized in Appendix B.

In order to identify some of the constants and potentially confounding variables, the general environmental conditions were given brief consideration, notably the lighting. It should be recognized, however, that this in itself can be a topic of investigation, exclusive of all other aspects of the workstation set-up. Nevertheless, it is necessary to take note of the existence of such variables, and appreciate their possible influence in determining how an individual operator might choose to adjust the components of a VDT workstation, and sit at it.

The values of illuminance ranged from 430 - 800 lx, equivalent to 40 - 80 fc. The literature (RQQ, 1980) recommends that levels be maintained between 300 - 1000 lx, or 30 - 100 fc, for the given office setting. The Hydro levels, therefore, fall within the suggested limits.

No measures were taken for noise level or atmospheric conditions.

Quantitative Data

Prior to performing any calculations involving the photographic data, a preliminary reliability check was conducted to verify the accuracy of the scale factors and information extracted from the slides. Actual (real-life) values for workstation dimensions were compared with slide-originated values. The values were found to be within 5 to 6% of one another for all dimensions, corresponding to an accuracy of no less than 94%, which is acceptable for these particular measures.

This introduces a possible limitation into the investigation; there
is some room for error in using 2-dimensional slides to analyze a 3-dimensional subject. It is assumed that the operator sits in an approximately symmetrical manner, thus presuming that any deviations in the frontal plane are minimal, and will not affect the overall results in any significant way.

The digitizer values were taken in the form of X, Y coordinates, (cartesian). From these values it was possible to determine joint angles, joint reactive forces and joint reactive moments. Angle measurements could be determined in two ways. The first method was direct measurement from either the projected image itself, or a graphic representation thereof. The second approach involved the simple insertion of the relevant segment endpoint values into the formula \( \theta = \arctan \frac{Y}{X} \). Both methods were used and the results compared. In the event of a discrepancy of more than five degrees, the angles were re-measured. Table 1 summarizes the data extracted from the slides, for both the workstations and the operators.

Joint reactive forces represent the magnitude of tensile forces required in muscles and ligaments holding a joint together, and the shearing and compressive forces acting on bone contact surfaces. Joint reactive moments, or torques, represent the strength moment required by specific muscles to maintain posture (Chaffin, 1982).

The model shown in Figure 3 is actually a multi-link, co-planar static model, in which reactive forces and moments can be added as vectors to adjacent joints. Thus, the computational procedure involved first, the solving of the equilibrium equations for the most distal joint, the wrist, (the load here being the weight of the hand). The resulting values were then used to solve for the conditions of the next adjacent joint, being the elbow. The procedure was continued until all
### Table 1

Workstation and Operator Dimensions for Ontario Hydro Subjects*

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Range</th>
<th>Mean</th>
<th>S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>worksurface height</td>
<td>64.0 - 78.2</td>
<td>70.38</td>
<td>4.4</td>
</tr>
<tr>
<td>underside clearance</td>
<td>61.0 - 74.2</td>
<td>65.7</td>
<td>3.9</td>
</tr>
<tr>
<td>seat pan height</td>
<td>45.7 - 55.6</td>
<td>51.87</td>
<td>2.45</td>
</tr>
<tr>
<td>screen height (centre)</td>
<td>77.7 - 111.5</td>
<td>93.3</td>
<td>7.7</td>
</tr>
<tr>
<td>home row height</td>
<td>64.7 - 89.6</td>
<td>76.36</td>
<td>6.6</td>
</tr>
<tr>
<td>backrest centre height</td>
<td>66.7</td>
<td>70.5</td>
<td>2.2</td>
</tr>
<tr>
<td>sitting height</td>
<td>112.0 - 140.8</td>
<td>128.0</td>
<td>7.05</td>
</tr>
<tr>
<td>eye height</td>
<td>99.5 - 125.5</td>
<td>114.7</td>
<td>8.7</td>
</tr>
<tr>
<td>shoulder height</td>
<td>82.0 - 111.0</td>
<td>97.74</td>
<td>8.2</td>
</tr>
<tr>
<td>elbow height</td>
<td>52.3 - 85.0</td>
<td>65.7</td>
<td>8.3</td>
</tr>
<tr>
<td>knee height</td>
<td>44.3 - 64.7</td>
<td>56.6</td>
<td>5.3</td>
</tr>
<tr>
<td>popliteal height</td>
<td>34.3 - 54.8</td>
<td>49.0</td>
<td>5.8</td>
</tr>
<tr>
<td>thigh clearance</td>
<td>10.7 - 18.5</td>
<td>14.7</td>
<td>1.8</td>
</tr>
<tr>
<td>knee clearance</td>
<td>6.2 - 14.8</td>
<td>9.66</td>
<td>5.8</td>
</tr>
<tr>
<td>visual distance</td>
<td>20.7 - 56.0</td>
<td>42.2</td>
<td>7.7</td>
</tr>
<tr>
<td>visual angle</td>
<td>16.0 - 54.0</td>
<td>27.1</td>
<td>9.76</td>
</tr>
<tr>
<td>keyboard slope</td>
<td>10, 20</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>screen angle (from vertical)</td>
<td>0, 5</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>head/neck angle (from vertical)</td>
<td>0 - 51</td>
<td>22.33</td>
<td>1.5</td>
</tr>
<tr>
<td>head/neck angle (from horizontal)</td>
<td>60 - 94</td>
<td>76.9</td>
<td>11.5</td>
</tr>
<tr>
<td>trunk angle (from vertical)</td>
<td>(-20.) - (+26)</td>
<td>-1.8</td>
<td>13.5</td>
</tr>
<tr>
<td>trunk angle (from horizontal)</td>
<td>80 - 102</td>
<td>91.95</td>
<td>2.1</td>
</tr>
<tr>
<td>shoulder angle (from vertical)</td>
<td>(-30.) - (+37)</td>
<td>9.76</td>
<td>12.7</td>
</tr>
<tr>
<td>shoulder angle (from horizontal)</td>
<td>65 - 95</td>
<td>83.26</td>
<td>9.4</td>
</tr>
<tr>
<td>forearm+hand angle (from horizontal)</td>
<td>0 - 43</td>
<td>16.5</td>
<td>14.0</td>
</tr>
<tr>
<td>elbow angle in crook of arm</td>
<td>45 - 115</td>
<td>88.5</td>
<td>18.2</td>
</tr>
<tr>
<td>seat, pan angle (from horizontal)</td>
<td>0 - 11</td>
<td>4.38</td>
<td>3.8</td>
</tr>
<tr>
<td>seat depth (front to back)</td>
<td>38.1 for all</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>backrest angle (from vertical)</td>
<td>(-20.) - (+10.5)</td>
<td>12.14</td>
<td>8.0</td>
</tr>
<tr>
<td>backrest length</td>
<td>2.92 for all</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

* taken from slides and direct measurements

@ standard deviation

+ distances are in centimeters, angles are in degrees (negative angles are behind the vertical plane, positive angles are in front)

Note: for keyboard slope and screen angle, there were only two adjustments, depending on whether the hardware was Micom or Wang (i.e., for Micom, the values were 20° and 5° respectively, and for the Wang system the values were 10° and 0° (upright).
Figure 3. A multi-link, co-planar, static model of the operator. Shown are reactive joint forces \( (R) \) and reactive joint moments \( (M) \). \( W \) represents the weight of each segment acting downward at the center of mass of the given link, due to the force of gravity.
the forces and moments had been determined for all links of interest in the system (Chaffin, 1982).

For the reactive forces of each joint,

\[ \varepsilon R_j = 0 \]  
\[ \text{and} \varepsilon R_j = R_{j-1} + W_L \]  

where:

- \( R_j \) = reactive forces at each joint
- \( R_{j-1} \) = reactive forces at previous adjacent joints in the system
- \( W_L \) = weight of each link, L (kg)

In this particular situation, the joint angles (\( \theta_j \)) had to be taken into account when estimating the moment arms, because the links, or segments, of the body are not parallel. Hence, the equation for the joint reactive moment equilibrium was expressed as:

\[ M_j = M_{j-1} + (j_{CM} (\cos \theta_j) W_L) + (j_{j-1} (\cos \theta_j) R_{j-1}) \]  

where:

- \( M_j \) = reactive load moment at each joint \( j \)
- \( j_{CM} \) = distance from joint \( j \) to the centre of mass (CM) of link \( L \)
- \( \theta_j \) = postural angles of links at each joint \( j \) with respect to the horizontal axis*
- \( W_L \) = weight of each body segment or link \( L \) (kg)
- \( j_{j-1} \) = segment link length from joint \( j \) to adjacent joint \( j-1 \)
- \( R_{j-1} \) = reactive force at previous adjacent joint \( j-1 \)

Note: * These values originate from standard anthropometric data (see Appendix D); \( W_L \) values were taken as percentages of total body weight, and distances as percentages of segment lengths.
* The horizontal axis is taken with respect to the frontal plane, which may be either on the right or the left, depending on which way the subject is facing, (see Figure 3).

Upon a closer examination of the equations, it can be seen that the joint reactive forces simply become the reaction forces due to the force of gravity (9.8 m/s²) acting on the weight of the segment. This is to be expected since the "activity" is basically static rather than dynamic. In addition, eq. 3 is merely an expanded and situation-specific variation of the formula \( MF = F \times a \); i.e., the torque (moment of force) is the product of the force and the moment arm, (force arm). The resulting values from the computations can be seen in Table 2.

Using (for a comparative guideline) the results for the 4 subjects who most closely approximated the biomechanically correct posture, the postures adopted by the remaining 17 subjects can be evaluated accordingly. Shown in the chart below are the relative joint reactive moments for the 4 selected subjects. Also note the last column which has values for the "ideal" posture as seen in the model in Figure 2.

<table>
<thead>
<tr>
<th>Joint</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>wrist</td>
<td>0.682 Nm</td>
<td>0.63 Nm</td>
<td>0.6 Nm</td>
<td>0.682 Nm</td>
<td>0.473 Nm</td>
</tr>
<tr>
<td>elbow</td>
<td>3.75</td>
<td>3.78</td>
<td>3.73</td>
<td>3.7</td>
<td>2.72</td>
</tr>
<tr>
<td>shoulder</td>
<td>3.2</td>
<td>4.6</td>
<td>4.19</td>
<td>4.98</td>
<td>4.2</td>
</tr>
<tr>
<td>neck</td>
<td>2.81</td>
<td>1.37</td>
<td>2.10</td>
<td>-0.5*</td>
<td>1.45</td>
</tr>
<tr>
<td>hip</td>
<td>-30.31*</td>
<td>42.38</td>
<td>-42.38*</td>
<td>-42.38*</td>
<td>17.6</td>
</tr>
</tbody>
</table>

*negative sign indicates direction

The values for the four subjects are higher than those for the model for every joint. Referring to Table 2b, it is clear that the mean
Table 2a
Relative Joint Reactive Forces (R)

<table>
<thead>
<tr>
<th>Joint</th>
<th>Segments Involved</th>
<th>Reactive Forces</th>
</tr>
</thead>
<tbody>
<tr>
<td>wrist</td>
<td>hand</td>
<td>(0.6% of TBW (kg)) (9.8 m/s²)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>= 5.88N</td>
</tr>
<tr>
<td>elbow</td>
<td>hand, forearm</td>
<td>(2.2% of TBW (kg)) (9.8 m/s²)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>= 21.56N</td>
</tr>
<tr>
<td>shoulder</td>
<td>hand, forearm, arm</td>
<td>(5%) of TBW (kg) (9.8 m/s²)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>= 49N</td>
</tr>
<tr>
<td>neck</td>
<td>head, neck</td>
<td>(8.1% of TBW (kg)) (9.8 m/s²)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>= 79.38N</td>
</tr>
<tr>
<td>hip</td>
<td>upper body</td>
<td>(67.8% of TBW (kg)) (9.8 m/s²)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>= 664.44N</td>
</tr>
</tbody>
</table>

# TBW is total body weight; percentage values are from Dempster via Miller & Nelson; in Winter, 1979, Table A.2, pp.151,152.

Table 2b
Relative Joint Reactive Moments (M)

<table>
<thead>
<tr>
<th>Joint</th>
<th>Mean M*</th>
<th>S.D.@</th>
<th>S.E.+</th>
</tr>
</thead>
<tbody>
<tr>
<td>wrist</td>
<td>0.604 Nm</td>
<td>0.066</td>
<td>0.015</td>
</tr>
<tr>
<td>elbow</td>
<td>3.578</td>
<td>0.292</td>
<td>0.067</td>
</tr>
<tr>
<td>shoulder</td>
<td>4.045</td>
<td>0.91</td>
<td>0.21</td>
</tr>
<tr>
<td>neck</td>
<td>1.635</td>
<td>1.255</td>
<td>0.29</td>
</tr>
<tr>
<td>hip</td>
<td>-11.464</td>
<td>43.116</td>
<td>9.89</td>
</tr>
</tbody>
</table>

* n=21
@ standard deviation
+ standard error of the mean

Note: the ranges of torque values for each of the joints are as follows:
- wrist ....... 0.5 - 0.682 Nm
- elbow ....... 2.8 - 3.81 Nm
- shoulder ... 3.2 - 5.36 Nm
- neck ......... 0.38 - 3.6 Nm
- hip .......... 24.26 - 72.30 Nm

(absolute values)
values for the whole subject pool also exceeded those for the ideal, except for the hip.

The obvious conclusion appears to be that by employing the ideal, optimum postures, the reactive torques at the joints will decrease; this is a desirable effect, because it implies that a lesser degree of effort is required to be exerted by the active muscles involved. As a result, postural maintenance should be less fatiguing and less stressful.

Because relative percentages of weight and distance were used, the results are, of course, relative values. (The same applies for Figure 2).

It is important to recognize the use of body segment parameter data in the calculations as a possible limitation to the study. The data are for approximately "average" females and, therefore, are only estimates for the subjects in this investigation. Other subject limiting factors can include age and race, as well as somatotype.

Knowing the values for R and M may allow for the comparison of the subjects with recognized standards for maximum loads. Presently, there is an unfortunate absence of such data in the literature pertaining to the seated and (externally) un-loaded individual. Information is currently available primarily for maximum loads during lifting tasks and manual materials handling. Future research might possibly be directed toward establishing similar standards for the seated person.

The calculations shown here are at least indicative of the potential forces that may be placed on certain body parts. Considering that 1N represents a force of 1 kg exerted at a rate of 1 m/s², one may appreciate the potential effects of a force as great as 644.44N, as was found at the hip.
The statistical analysis of the data collected at Ontario Hydro, (as compared to the literature recommendations), revealed no particular trends. Some parameters showed significant differences while others did not.

For purposes of comparison, the values provided by Cakir et. al. (1980) were used. When not available or provided, the most recent of Grandjean's suggestions were used instead. (No one single year can be mentioned here, since each of Grandjean's publications did not deal with all of the dimensions concerned.) These are the most widely consulted and quoted sources in use in North America (see Table 3).

The major differences were found to occur among the physical workstation dimensions, (p<.05), rather than for the user dimensions. This means that for several aspects of component adjustability, the Ontario Hydro workstations failed to meet the published guidelines. However, the values shown in Appendix C demonstrate the enormous variability among recommendations that can be found in various publications. Every researcher has arrived at differing conclusions as to how a VDT workstation can best be arranged.

It is almost inevitable that the Ontario Hydro terminals conform to at least some of the literature suggestions. Even where differences are noted, they are often no more than a few millimeters one way or another. For some dimensions these small differences can be crucial, and yet for others they are of no consequence.

Cross-correlations were performed, using the 19 human dimensions against the 26 workstation dimensions, (which are listed and illustrated in Appendix E). No significant relationships arose for the Ontario Hydro workstations as a result of this test, (r(43)=.0026, p<.05). A correlation coefficient is merely a measurement of the existence or absence of
a (linear) relationship between variables and provides some indication of the strength of this relationship. It cannot demonstrate causality, however, although it may show common linkage to other events or variables.

Table 3
Workstation Dimensions and Operating Posture Characteristics of Subjects Compare to the Literature

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Subject Means</th>
<th>Literature Means</th>
<th>t(p&lt;.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td>worksurface height</td>
<td>70.38</td>
<td>72.5</td>
<td>2.988</td>
</tr>
<tr>
<td>underside clearance</td>
<td>65.7</td>
<td>62.0</td>
<td>2.978</td>
</tr>
<tr>
<td>seat pan height</td>
<td>51.87</td>
<td>46.0</td>
<td>12.757</td>
</tr>
<tr>
<td>seat pan angle</td>
<td>4.38</td>
<td>16.0</td>
<td>3.381</td>
</tr>
<tr>
<td>screen centre height</td>
<td>93.3</td>
<td>107.5</td>
<td>8.022</td>
</tr>
<tr>
<td>screen angle (from vertical)</td>
<td>0, 5</td>
<td>0</td>
<td>4.472</td>
</tr>
<tr>
<td>homerow height</td>
<td>76.36</td>
<td>73.5</td>
<td>4.310</td>
</tr>
<tr>
<td>backrest height</td>
<td>70.0</td>
<td>69.36</td>
<td>2.290</td>
</tr>
<tr>
<td>visual angle</td>
<td>27.1</td>
<td>15.0</td>
<td>2.108</td>
</tr>
<tr>
<td>visual distance</td>
<td>42.2</td>
<td>47.5</td>
<td>13.31</td>
</tr>
<tr>
<td>eye height</td>
<td>114.7</td>
<td>107.5</td>
<td>12.806</td>
</tr>
<tr>
<td>shoulder height</td>
<td>97.74</td>
<td>90.45</td>
<td>3.99</td>
</tr>
<tr>
<td>knee height</td>
<td>56.6</td>
<td>50.25</td>
<td>5.34</td>
</tr>
<tr>
<td>popliteal height</td>
<td>49.0</td>
<td>45.0</td>
<td>3.07</td>
</tr>
<tr>
<td>thigh clearance</td>
<td>14.7</td>
<td>13.0</td>
<td>15.9</td>
</tr>
<tr>
<td>knee clearance</td>
<td>&lt; 9.66</td>
<td>18.5</td>
<td>8.874</td>
</tr>
<tr>
<td>head/neck inclination</td>
<td>22.33</td>
<td>22.5</td>
<td>2.218</td>
</tr>
</tbody>
</table>

# shown are those variables for which there occur statistically significant differences

* n=21

Note: heights and distances are measured in centimeters; angles are in degrees.
Discussion

It is evident from Table 1 that the Hydro operators have demonstrated a wide variety and range of preferences concerning the adjustment of components at a video display terminal workstation. Each individual may or may not meet the recommendations of any given source, for any one specific parameter. The tremendous variability in the literature makes it rather difficult to decide which sources are best for serving as guidelines, as almost all the values seem to have been generated and substantiated by valid research. Appendix C provides a summary of the recommendations found in most of the major sources currently available.

There seems to be a general agreement that adjustability and flexibility are of the utmost importance. Individual needs must be catered to. Most experts strongly advocate full support for the body via external means, including backrests, armrests, and especially footrests - something that every Ontario Hydro workstation was found to be lacking.

Seating at work should be a means to an end. It assists in the performing of a task, and is not the task itself. A seated individual is biomechanically unstable, thereby calling for the exertion of muscular effort to achieve stability. While a seated person is, for the most part, in a relatively static state, (in terms of gross motor activity), the muscles involved are in an active state. Posture must be maintained against gravity by muscular exertion. The natural end result to this is fatigue. Changes in posture can delay the onset of muscle fatigue brought about by work (Drury & Coury, 1982, Branton, 1969; Floyd & Roberts, 1958).
Although the body (torso) can be stabilized by employing the postural muscles, the gaining of stability can also be achieved by the use of external aids and rests. There is much debate as to the usefulness of armrests for chairs at VDT stations, in that many feel that they simply get in the way. Chaffin (1973) considers that "one of the most important aspects of using arm rests is in reducing the torque on the shoulder due to the arm weight". However, in the case of a clerical worker, arm rests may prove to be a disadvantage because, as Drury & Coury (1982) have shown, they can interfere with such activities as drawer opening. They can also restrict the movement of the seated individual. Footrests, which were omitted at the Ontario Hydro workstations examined, are extremely valuable.

Branton (1969) noted in his study that knee-crossing was often demonstrated. He suggested that this occurred because it reduces the tendency of the pelvis to rotate and, in effect, creates a locking system with the adducted thighs. When the legs are stretched out in front of the body and crossed at the ankles, a similar result is seen. The thighs are once again adducted, the knees are locked, and the potential rocking action of the pelvis is counter-acted. As well, out-stretched legs behave as brakes, preventing the body from sliding forward off the chair. Such patterns of behavior were observed in most of the subjects in this study, as well.

Footrests would alleviate the need for crossing the knees and ankles, and stretching the legs forward, if properly used. Compressive forces on the buttocks can nearly double when one sits in a cross-legged fashion. These high pressures deem it necessary to alter the posture with some frequency so that relief may be had (Tichauer, 1973, 1978). Footrests also help prevent excessive pressure from being placed on the
underside of the thighs; pressure that could cause ischemia, numbness, and general discomfort over time (Ayoub, 1973).

Cakir et al. (1980) have identified certain movements as being particularly stressful to the back while sitting: bending, stretching, leaning and twisting. There was very little movement of this nature noted among the Hydro subjects. Hunting et al. (1980) identified a relationship between pain and stiffness experienced in the shoulder girdle and the extent of the opening of the angle inside the elbow, i.e., between the forearm and the upper arm. They are positively correlated variables, so that as the angle increases beyond 90°, so does the amount of discomfort. Joints tend to operate best and most efficiently around their mid-range point, the elbow and shoulder being no exception. The subjects studied in this investigation demonstrated a range of 45 - 115° for this particular angle, with a mean of 88.5°. (See Table 1.) They generally met the mid-range criterion.

Many of the subjects had their heads positioned in a forward-leaning manner, some as much as 51° below the vertical. Kumar and Scalf, in their 1979 report, studied seated women operators performing precision tasks. Their findings emphasized the hazards of such a forward inclination of the head and neck. Several events may occur as a direct result: the lordosis of the spine is reduced, (previously illustrated in Figure 1); the moment arm on which the weight of the trunk acts is lengthened, thereby causing an increase in the resulting torque; the moment which must be developed by muscles controlling this flexion, in order to maintain posture, rises significantly. (See Figure 4.)
Figure 4: Forces acting on the spine in resting and in forward inclined postures. (After Kumar & Scaife, 1982.)

\[ F_H \] = the force due to the weight of the head and neck
\[ F_T \] = the force due to the weight of the torso
\[ F_C \] = the force due to the cervical muscles in the neck
\[ F_L \] = the force due to the lumbar muscles in the lower back
\[ a_c \] = lever arms for the cervical muscles
\[ b_L \] = lever arms for the lumbar muscles
\[ a_H, b_H \] = lever arms for the head and neck
\[ b_T \] = lever arms for the torso

In the inclined position, \[ F_C = F_H \frac{a_H}{a_C} \] and \[ F_L = F_T b_T + F_H b_H \]

Therefore, when the head and torso are inclined forward, there is an increase in both \[ F_C \] and \[ F_L \], due to increases in \[ a_H, b_T, \] and \[ b_H \].
One suggestion that has been made in an attempt to eliminate this sort of problem is the use of a tilting seat, as proposed by Mandal (1976, 1982). As Mandal explains, most forms of seated work utilize the forward bent posture. The tilting chair would have a tilt of 15° forward, thereby "pushing one forward to a more comfortable and relaxed position for bent-forward work... The pelvis tilts forward of its own accord and lumbar lordosis is re-established."

In his 1970 report, van Wely discussed three rules drawn from functional anatomy and muscular physiology, concerning undesirable postures: 1) avoid overloading of the muscles and tendons, 2) avoid loading joints in an uneven or unbalanced manner, and 3) minimize the involvement of static loading of the musculature. Consequently, a list of 'bad postures' and corresponding hypothetical sites of pain, stiffness or other symptoms, (see Table 4), has been developed.

Table 4

<table>
<thead>
<tr>
<th>Posture</th>
<th>Probable Site(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>sitting without lumbar support</td>
<td>lumbar region</td>
</tr>
<tr>
<td>sitting without support for the back</td>
<td>lumbar region</td>
</tr>
<tr>
<td>sitting without good footrests of the correct height</td>
<td>knees, legs and lumbar region</td>
</tr>
<tr>
<td>sitting with the elbows rested on a working surface that is too high</td>
<td>trapezius, rhomboideus and levator scapulae muscles</td>
</tr>
<tr>
<td>head bent back</td>
<td>cervical region</td>
</tr>
<tr>
<td>trunk bent forward; stooping position</td>
<td>lumbar region and erector spinae muscles</td>
</tr>
<tr>
<td>any cramp position</td>
<td>the muscles involved</td>
</tr>
<tr>
<td>maintenance of any joint in its extreme position</td>
<td>the joint involved</td>
</tr>
</tbody>
</table>

Extracted from Applied Ergonomics, 1(5), December 1970. "Design and Disease" by P. van Wely
Earlier this year (1983) Grandjean et al. released the results of a study in which female subjects were allowed to adjust the VDT workstation components however they felt necessary, and adopt the corresponding working postures. It was found that even after all the years of research, the subjects still chose as their preferences body postures and workstation adjustments which differed, often dramatically, from those recommendations found in textbooks and other publications. For example, the results revealed that, "in practice, operators with preferred workstation settings tend to lean backward, with trunk inclination between 97 and 121 degrees (from the horizontal). Even on fixed workstations, the same operators show a clear tendency to lean backward." These findings are in agreement with those of the present study, in which backward inclinations were frequently noted, from 94 to 102 degrees.

An important point to consider is the actual relationship between the ergonomic recommendations and personal preferences of individual operators. It seems that user preference continually overrides the supposed best arrangements (Stammerjohn et al., 1981; Grandjean et al., 1983). The literature suggests, even for one given population, do not all agree with one another. Nor do they appear to be based on any practical mathematical formulae or equations. Rather, they are generated from either i) studying operators at work; or ii) by assuming the model (as in Figure 2) is truly the healthiest and most efficient, and assigning values accordingly, in keeping with anthropometric data. The conflict between theory and reality provides yet another area for further future investigations.

Continuous work at a video display terminal is characterized by constrained body postures resulting from the maintenance of relatively
fixed positions of the body parts while operating the equipment and viewing the screen and source documents. These fixed postures are associated with large static loads, especially in the neck, shoulders, arms and back.

As workstation construction differs more and more from natural body configurations, the static efforts increase accordingly. Ultimately, efficiency and productivity will diminish as physical discomfort and fatigue begin to take their toll.

It is this sentiment which leads to the recommendations which follow.
Recommendations

The first major objective of this study was to examine the workstations at a sampling of Ontario Hydro offices and suggest ways, (suitable for immediate implementation), in which they might be improved, in terms of the comfort and well-being of the operator. Having identified the most prominent physical complaints via the survey and literature, and having equated the workstations to the endless prototypes as advised by the experts, there are three conclusions which can be highlighted at this time:

1. Ergonomic recommendations to date, (based on anthropometric data of an upright user), may not necessarily be appropriate. Most operators do not adopt this ideal posture, thereby rendering the recommendations based upon such an assumption useless.

2. All of the stations meet one of the most strongly advocated criteria, namely, total adjustability. Nevertheless, the complaints so often reported in the literature still remain. The fundamental problems persist, and new ones are constantly arising. (This is probably a result of the first conclusion).

3. Being limited, essentially, to the existing facilities and hardware currently used at Ontario Hydro, there are few ways in which to improve upon Hydro's workstations and reduce the incidence of physical discomfort presently experienced by the operators.

The most useful recommendation that can be made under these circumstances is for the inclusion of footrests, which have been omitted in all the Hydro stations examined. It has already been noted in the discussion that footrests are very beneficial components to have.

The physical capacities and limitations of the human body may be controlled, to a certain extent, by a variation of the domino effect.
This implies that no single aspect of physical discomfort reported by
the operators is mutually exclusive of any other.

The basic principle involved with this effect is that by
alleviating even one small part of the total problem associated with the
operation of the VDTs from a sitting position, other aspects of the
problem may also be remedied, as a result. The effect is potentially
additive.

Therefore, the use of footrests, which would initially serve to
eliminate the need for leg crossing and bracing, would not only make the
legs themselves more comfortable but help to reduce the compressive
forces exerted on the buttocks and underside of the thighs.

With a reduction in these stresses, ischemia is less likely to
occur. (Ischemia is responsible for the numbness and tingling sensation
due to a diminution in blood flow, caused by restricting the
circulation.) The avoidance of ischemia should in turn lessen the need
to adopt a compensatory posture wherein the operator sits perched
forward at the front edge of the seat in order to remove the pressure
from the thighs.

This type of chain reaction of solutions may extend itself
throughout the entire body, or remain a localized event. In either
case, any positive effects, regardless of how limited or confined they
might be, are better than no improvements at all.

The desirable effect of the addition of footrests to the
workstation is to encourage a more biomechanically sound posture. The
footrests would eliminate the need to sit perched on the chair, and
thereby reduce the kyphosis and enhance the lordosis. In addition,
proper sitting will retain the appropriate reach envelopes and visual
distances. Incorrect seating would require that an operator adjust
his/her head accordingly to see the screen and source documents.

The particulars of footrest placement are a topic of debate. There are those who feel that a footrest should be attached to the desk itself, or to the base of the chair, (Cakir et. al., 1980; Woodson, 1981). Some have even suggested that it be permanently fastened to the floor. But the most widely agreed upon recommendation, and the one in keeping with the 'law of adjustability', is to have a footrest separate from all other workstation components. This permits each operator to locate it where he/she feels it is most suitable.

Appendices C and E illustrate the general placement of footrests at a VDT station, and provide information regarding ranges and direction of adjustability. Personal preferences usually override literature recommendations for any given situation.

In addition to providing immediate recommendations for the specific sites examined, this investigation was also initiated so that recommendations could be made for the design of future workstations, which would utilize the same or similar hardware as is used at the present, (with only a few minor modifications).

Judging from the number and frequency of articles appearing in current journals and publications, the problems of operator comfort and health at VDT workstations are receiving more and more attention, but are no closer to being solved than they were when such work settings originated. The major achievement since then seems to be the identification of more problem areas, while little has been done to effectively correct them.

With these considerations in mind, it is suggested here that perhaps the past several years of investigation have focused too
intently on improving upon a situation which cannot really be improved as it presently exists. As a result, what follows is a proposal for a new approach to designing a display terminal-centered working environment.

The new workstation set up is based on a layout that has long been in use in other work situations, primarily industrial. The basic tenet involved is the application of a sit-stand station to this specific situation. Such an arrangement would afford the operator numerous advantages.

As previously mentioned, man is not, by nature or design, a sedentary creature. The human body is built for movement. Any static posture can result in discomfort and dissatisfaction after an extended period of time, even lying prone. The sit-stand variations would allow an individual to change his/her gross body position from time to time, while maintaining the relative placement of the workstation components required for the best visibility and easiest operation.

The specific postural transformations involved will provide a user with an opportunity to rest the taxed musculature and weight-bearing body regions. The sit-stand exchange is especially valuable when an operator is 'on duty' for lengthy periods of time.

With reference to Figure 1, recall that the standing position provides the shortest lever arm with which the weight of the upper body is supported upright, (from the lumbar spine). This means that the torque is at its smallest value. It increases when the sitting position is assumed.

Standing gives one a chance to stretch the legs and torso, and take the stress off the ischial tuberosities and underside of the thighs. The seat pan carries roughly 65% of the total body weight, 50% resting on
the area under the ischiae alone, with the other 15% distributed elsewhere. In addition, standing will enhance the circulation and minimize the chances for ischemia to occur.

On the other hand, sitting is often a welcome alternative to standing. It takes the weight bearing responsibilities away from the legs and the lower back, and reassigns the task primarily to the buttocks.

The fundamental design guidelines for a sit-stand workstation are not unlike those for a traditional seated workstation:

- avoid excessive trunk movements
- provide elbow room
- utilize 'normal' (mid-range) reach areas, not the maximum
- allow for a variety of minor positional changes
- keep the work surface height at (or slightly below) elbow height
- establish location of visual displays with respect to eye position
- provide a stable base of support for the seat
- arrange components to allow head to be maintained upright, or within a 30° forward inclination
- arrange components to allow shoulders to remain at their 'natural' resting height – avoid shrugging
- provide an adjustable footrest

While an examination of Ontario Hydro stations did not reveal any significant relationships or correlations between body (anthropometric) measurements and workstation dimensions, other researchers (Singleton, 1972; Nertney & Bullock, 1976; Roozbazar, 1978; Kumar & Scab, 1979)
have identified certain consistencies. What they have found is reflected in the general considerations listed above.

Tichauer (1973) commented that "whenever work is possible in either seated or standing positions, work surface and seating design should permit change of posture without change of musculoskeletal configuration". This suggestion for such a station can be seen in Figure 5a. In this example, the working height should allow for a relaxed position of the upper arms, (McCormick & Sanders, 1982).

Woodson (1960, 1981) has similarly suggested a way in which a sit-stand station can be arranged. (See Figure 5b.) Notice that in both instances, (ie: Tichauer and Woodson), the work surface is at elbow height and footrests are provided.

Taking into account these two models, as well as certain workstation dimensions and anthropometric data found in the literature, a prototype sit-stand workstation has been generated for use with VDTs, as illustrated in Figure 6.

The actual components, (screen, keyboard, source document holder), are placed on a single surface, as before. This surface is supported on a cylindrical base offering maximum leg room, and can be raised or lowered about a central point on the base (item 1). This height is best controlled by a hydraulic lift mechanism or crank of some sort, which can be easily operated by foot (item 2).

On the lower portion of the base a footrail is located, (item 3), which can also be adjusted in the vertical plane. The rail should be constructed with a flat, non-skid surface on which the feet may rest while one is either standing or sitting. A similar rest can be found on the chair stand as well (item 4).

The seat itself should be fully adjustable, just as for the
Figure 5. Sit/stand workstation variations.

(After Tichauer, 1973.)

(After Woodson, 1981.)
Figure 6. Prototype Sit/Stand Workstation
traditional workstations; (shown in Appendix E). The seat pan must have the ability to be raised or lowered, as should the backrest, (items 5 and 6). The backrest must also be able to tilt forward and backward about its vertical axis (item 7). A seat inclination (item 8) of 3 to 5° is generally recommended. The seat itself should measure approximately 38 – 40 cm deep and 40 – 45 cm across the front. Note the rounded edge at the front of the seat. An angle of 105° is the norm between the surface of the seat and the backrest.

This type of workstation has several advantages, in addition to those previously discussed. In particular, the work may be performed while the operator assumes any one of three postures: sitting, standing, or reclining against the chair in a half standing, half sitting manner. No matter which position is used, an operator need set up the components to his/her liking only once. After that, the station may be moved as a single unit. Of course, the station may also be rearranged as required to suit any number of different users.

The space requirements for the sit-stand station are not much greater than those for a strictly sitting-oriented station. Because this design is more flexible, more changes are allowed in a user’s body position, without involving the occurrence of any extreme motions. That is, the general musculoskeletal configuration may remain, (as Tichauer suggests), but the stresses may be shifted from one body part to another.

The visual needs should not be affected by a change in position. They too, should adapt accordingly following the initial organization of the visual displays.

The problem of improving the health, comfort and well-being of the
VDT operator may begin to be overcome with the application of recommendations such as those included in this study. In addition, the value of these possible solutions must also be considered for other applications. It is estimated that three-quarters of all operatives in industrial countries have sedentary jobs (Grandjean, 1982b). Perhaps such workstations will find their place in other work settings.

The proposed sit-stand station must now receive the same thorough scrutinization that has been given to the traditional VDT workstation; its limitations must be identified and defined. What physical harm can potentially be suffered by a long-term user? How does one specific posture at this station compare to any other given posture? What sort of strains and forces are exerted on the supporting joints and musculature?

Grandjean (1982b) has labelled the study of such problems associated with workstations as the new challenges to biomechanics and anthropometrics - "to develop the proper design of these man-machine systems in order to fit the essential workplace dimensions to the body size as well as to the involved body functions. Yet the main objective still remains the same; fitting the working conditions to the man."
Summary

This ergonomic evaluation of video display terminal workstations and operating postures was conducted using 21 female operators from Ontario Hydro as major subjects. In addition, the opinions of 688 clerical workers who operated VDTs were also considered.

Data was collected in four specific ways: i) a subjective survey was distributed among 1,918 clerical workers, 1,166 (61%) of whom returned completed and usable questionnaires. From those returned, 59% were VDT operators; ii) direct observations were made at 21 individual workstation stations, noting the general workstation configurations and gross operating postures of the employees at each of the stations; iii) direct measurements were taken for a number of physical dimensions at each of the 21 stations, and a light meter was used to record the illuminance; iv) photographic data was gathered with a 35 mm semi-automatic SLR camera, ASA 400 colour slide film, and an electronic digitizing system.

The survey, direct observations and photographic records all contributed to the qualitative data pool, while the direct measurements and slides provided quantitative data.

Analysis of the slides was performed on a numerics graphics calculator, using a standard carousel projector to project the slides.

The body was considered to be a link-segment model consisting of 8 links (or segments) and 7 joints. The analysis and evaluation of the data emphasized primarily the upper body, because it is the upper body regions which appear to be most greatly affected by the long-term use of VDTs in constrained postures, (as indicated throughout the literature and from the survey).

The results suggest that only 4 of the 21 major subjects actually adopted the most widely accepted proper posture. The survey results
strongly indicate that VDT operators experience a higher incidence of physical discomfort, the most common complaints being aches and soreness of the neck and shoulder areas. Upon comparing the workstation dimensions and particular numerical parameters of the operating postures of the Ontario Hydro subjects with the recommendations found in the literature, it appears that there are no significant differences or important discrepancies. (Refer to Table 3.) However, there is one serious omission that was observed at all stations examined - footrests.

There are 4 major conclusions that can be drawn from this study:

1. VDT operators appear to report a high incidence of physical discomfort as evidenced by the questionnaire results and substantiated throughout the literature.

2. Aches and soreness of the neck and shoulders is a significantly frequent complaint.

3. Ergonomic recommendations to date are not necessarily appropriate to VDT operators.

4. All stations examined in this study conform to the criterion of total adjustability, yet complaints still persist.

Recommendations have been made in two respects. Firstly, suggestions were put forward concerning ways in which the workstations examined could be improved upon in terms of enhancing the health and comfort of the operators. Footrests proved to be the most useful item to include. Secondly, recommendations were made for the design of a prototype workstation which offers features not presently available. The prototype, based on the philosophy of a sit-stand station also incorporates some existing VDT workstation features, or modifications thereof. Finally, suggestions for future avenues of research were
indicated. It is perhaps advisable to examine the sit-stand station as thoroughly as the traditional workstations have been scrutinized; for they also must have their limitations and the potential to cause harm to the long-term user if incorrectly employed. Such investigations must focus on the physical strains placed on the body, and the forces acting on the supporting musculature and joints. Hopefully, all the years of research will one day come together in successfully creating the ideal video display terminal workstation, suitable for the entire user-population.
References


Corlett, E.N. Anthropometry and Biomechanics, 1982.


Appendices
Appendix A

The checklist shown here was used as part of the on-site evaluation.

1. Is the underside of the desk free from obstructions? Y N
2. Is the general leg area free from obstructions? Y N
3. Are the components (screen, keyboard, etc.) detached to permit individual adjustability and arranging? Y N
4. Is a footrest provided? Y N
5. Is the seat height adjustable? Y N
6. Is the seat angle adjustable? Y N
7. Is a backrest provided? Y N
8. Is the backrest fully adjustable? Y N
9. Are adjustment mechanisms secure and protected from accidental or inadvertent release? Y N
10. Is the head generally upright or inclined forward? Y N
11. Is the cervical spine curved slightly forward? Y N
12. Are the thoracic and lumbar spines arched slightly forward? Y N
13. Are the upper arms approximately vertical? Y N
14. Are the forearms approximately horizontal? Y N
15. Are the thighs generally horizontal? Y N
16. Are the lower legs held roughly vertical? Y N
17. Has the operator avoided excessive twisting of the head or body? Y N
18. Are the feet resting flat on the floor or footrest? Y N
19. Note any other features of the workstation or operating posture of particular interest...
**Appendix B**

Summary of responses from the checklist (Appendix A).

<table>
<thead>
<tr>
<th>Question</th>
<th>Number of Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Y</td>
</tr>
<tr>
<td>1.</td>
<td>21</td>
</tr>
<tr>
<td>2.</td>
<td>21</td>
</tr>
<tr>
<td>3.</td>
<td>21</td>
</tr>
<tr>
<td>4.</td>
<td>-</td>
</tr>
<tr>
<td>5.</td>
<td>21</td>
</tr>
<tr>
<td>6.</td>
<td>21</td>
</tr>
<tr>
<td>7.</td>
<td>21</td>
</tr>
<tr>
<td>8.</td>
<td>21</td>
</tr>
<tr>
<td>9.</td>
<td>21</td>
</tr>
<tr>
<td>10.</td>
<td>15</td>
</tr>
<tr>
<td>11.</td>
<td>13</td>
</tr>
<tr>
<td>12.</td>
<td>11</td>
</tr>
<tr>
<td>13.</td>
<td>14</td>
</tr>
<tr>
<td>14.</td>
<td>12</td>
</tr>
<tr>
<td>15.</td>
<td>21</td>
</tr>
<tr>
<td>16.</td>
<td>8</td>
</tr>
<tr>
<td>17.</td>
<td>20</td>
</tr>
<tr>
<td>18.</td>
<td>6</td>
</tr>
</tbody>
</table>

19. In several cases (19), the operator's legs were crossed in one way or another, i.e.: at the thighs, knees or ankles. Seven subjects had their feet hooked over or wrapped around the chair base, one had her shoes off, and one wore a lead apron. At a brief glance, most operators appeared to be sitting in the 'standard' manner.
Appendix C

Literature Recommendations for VDT Workstation Dimensions
and Characteristics of Operator Posture, For Females

Following is a listing of the major dimensions most frequently reported in the literature, including the ranges of available data and mean values. In addition, the suggestions made by Cakir et al. (1980) and Grandjean are identified, as these were the sources used for comparative purposes in this study.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Range</th>
<th>Mean</th>
<th>Cakir</th>
<th>Grandjean*</th>
</tr>
</thead>
<tbody>
<tr>
<td>footrest slope</td>
<td>10-35°</td>
<td>22.5</td>
<td>10-15</td>
<td>25 (80)</td>
</tr>
<tr>
<td>screen height (centre)</td>
<td>55-160 cm</td>
<td>107.5</td>
<td>100-115</td>
<td></td>
</tr>
<tr>
<td>seat pan height</td>
<td>33-56 cm</td>
<td>44.5</td>
<td>45-52</td>
<td>34-53 (77,80,82)</td>
</tr>
<tr>
<td>knee clearance</td>
<td>11-20 cm</td>
<td>13.5</td>
<td>17-20</td>
<td>17 (80)</td>
</tr>
<tr>
<td>thigh clearance</td>
<td>13-30 cm</td>
<td>21.5</td>
<td>-</td>
<td>13 min. (63)</td>
</tr>
<tr>
<td>visual distance</td>
<td>30-100 cm</td>
<td>65.0</td>
<td>45-50</td>
<td></td>
</tr>
<tr>
<td>visual angle</td>
<td>0-45°</td>
<td>22.5</td>
<td>10-20</td>
<td>10-15 (80,82)</td>
</tr>
<tr>
<td>screen angle</td>
<td>-15 - +20°</td>
<td>2.5</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>keyboard slope</td>
<td>0-35°</td>
<td>17.5</td>
<td>5-15</td>
<td></td>
</tr>
<tr>
<td>homerow height</td>
<td>56.7-83 cm</td>
<td>69.85</td>
<td>72-75</td>
<td>64-83</td>
</tr>
<tr>
<td>eye height</td>
<td>64.5-116 cm</td>
<td>89.75</td>
<td>100-115</td>
<td></td>
</tr>
<tr>
<td>underside clearance</td>
<td>55-69 cm</td>
<td>62.0</td>
<td>65-69</td>
<td>53-61 (63,80)</td>
</tr>
<tr>
<td>work surface height</td>
<td>51.5-83.1 cm</td>
<td>67.3</td>
<td>72-75</td>
<td>65-78 (63,80)</td>
</tr>
<tr>
<td>backrest height (centre)</td>
<td>61.8-76.8 cm</td>
<td>69.36</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>seat pan angle</td>
<td>3-16°</td>
<td>9.0</td>
<td>-</td>
<td>16 (64)</td>
</tr>
<tr>
<td>backrest angle (from vertical)</td>
<td>13-48°</td>
<td>30.5</td>
<td>-</td>
<td>35-48 (64)</td>
</tr>
<tr>
<td>seat length</td>
<td>38.1-40.6 cm</td>
<td>9.35</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>seat depth</td>
<td>41-55 cm</td>
<td>48.0</td>
<td>-</td>
<td>41-55 (64)</td>
</tr>
<tr>
<td>head inclination</td>
<td>15-30° forward</td>
<td>22.5</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>backrest width</td>
<td>30 cm</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

* numbers in parentheses are the years of publications.
Appendix C. cont'd.

Listed below are the sources reviewed (fully referenced in the bibliography) in which values include in the preceding table were mentioned.

Alden et. al., 1972.
Andersson & Ortengren, 1974.
Bandini Buti et. al., 1980.
Bergman, 1980.
Buhmann, 1980.
Burandt & Grandjean, 1963.
Cakir et. al., 1980.
Canadian DCIEM, 1980.
Caron et. al., 1982.
Das & Grady, 1980.
Diffrient et. al., 1981a, b,
Finn, 1982.
Floyd & Roberts, 1958.
Galitz, 1980.
German DIN.
Helander, 1980.
Hunting et. al., 1980, 1981.
Koffler, 1982.
Appendix C. cont'd.

Lasden, 1981.
Mackay, 1981.
Maloney, 1981.
Mandal, 1976.
McCormick & Sanders, 1982.
Miller & Suther, 1981.
Murray et. al., 1981.
Nachemson & Elfstrom, 1970.
NIOSH, 1981.
Oborne, 1982.
Ostberg, 1981.
Sanders, 1981.
Shackel, 1980.
Shaffer, 1981.
Smith et. al., 1981.
Steelcase, 1981.
Tymán, 1981.
VanCott & Kinkade, 1972.
### Appendix D

Standard Anthropometric Data for "Average" Females

<table>
<thead>
<tr>
<th>Segment</th>
<th>Weight (as percent of total body wt.)</th>
<th>Distance to CM from proximal end</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>hand</td>
<td>0.6%</td>
<td>50.6%</td>
<td>0.1737 m</td>
</tr>
<tr>
<td>forearm</td>
<td>1.6</td>
<td>43.0</td>
<td>0.254</td>
</tr>
<tr>
<td>forearm &amp; hand</td>
<td>2.2</td>
<td>62.8</td>
<td>0.4445</td>
</tr>
<tr>
<td>upper arm</td>
<td>2.8</td>
<td>43.6</td>
<td>0.3378</td>
</tr>
<tr>
<td>upper limb</td>
<td>5.0</td>
<td>53.0</td>
<td>0.762</td>
</tr>
<tr>
<td>foot</td>
<td>1.4</td>
<td>50.0</td>
<td>0.2413</td>
</tr>
<tr>
<td>shank</td>
<td>4.5</td>
<td>43.3</td>
<td>0.3708</td>
</tr>
<tr>
<td>foot &amp; shank</td>
<td>6.1</td>
<td>60.6</td>
<td>0.6375</td>
</tr>
<tr>
<td>thigh</td>
<td>10.0</td>
<td>43.3</td>
<td>0.4572</td>
</tr>
<tr>
<td>lower limb</td>
<td>16.1</td>
<td>44.7</td>
<td>1.0998</td>
</tr>
<tr>
<td>head &amp; neck</td>
<td>8.1</td>
<td>43.3</td>
<td>0.2032</td>
</tr>
<tr>
<td>trunk (thorax, abdomen, pelvis)</td>
<td>49.7</td>
<td>50.0</td>
<td>0.588</td>
</tr>
<tr>
<td>head, neck &amp; trunk</td>
<td>57.8</td>
<td>66.0</td>
<td>0.7912</td>
</tr>
</tbody>
</table>

Sources: LeVeau, 1977; Winter, 1979; VanCott & Kinkade, 1972. (Original authors: Clauser, Dempster, Braune & Fischer)
Appendix E

Traditional measurement sites for VDT workstations and operating postures. The numbered items below correspond to the numbered items shown in the figures which follow.

1. height to screen centre
2. keyboard home row height
3. worksurface height
4. height to underside of desk (clearance)
5. knee clearance, from patella to underside
6. knee height (to patella)
7. popliteal height
8. footrest angle range
9. elbow angle
10. height from seat pan to centre of backrest
11. seat pan height
12. chair back height (to centre)
13. elbow rest height
14. shoulder height (to acromion)
15. eye height
16. sitting height
17. visual distance
18. screen angle
19. knee well depth
20. keyboard angle
21. visual angle
22. thigh clearance
23. seat pan angle
24. back angle (adjustability),

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Appendix F

The following questions are the items of relevance to this study, which were embedded within a broader survey, (as described in the methods). Subjects responded using semantic scales from 1 to 5, each value having a different interpretation:

| Eye strain (redness, irritation, dryness, tenderness, or throbbing) |
|-------------------|-------------------|-------------------|-------------------|-------------------|
| Blurred vision (trouble focusing, hazy image) |
| Headaches (migranes, dull or splitting headaches) |
| Aches in neck or shoulder |
| Aches in arms |
| Aches in back |
| Aches in legs |
| Sore fingers |
| Unusually intense fatigue |
| Unusual irritability |
| Restlessness |
| Rashes on face, arms & hands |

| ON MY PRESENT JOB I EXPERIENCE: |
|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| Never | Up to 25% of the time | Up to 50% of the time | Up to 75% of the time | More Than 75% of the time |
| (1) | (2) | (3) | (4) | (5) |
Appendix F. cont'd.

**HOW SATISFIED ARE YOU?**

<table>
<thead>
<tr>
<th>Very Satisfied</th>
<th>Satisfied</th>
<th>Cannot Decide</th>
<th>Dissatisfied</th>
<th>Very Dissatisfied</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
</tr>
</tbody>
</table>

- With the space and arrangement of your work station
- With the noise level at your work station
- With the light illumination level at your work station
- With the office furniture you use
- With the office mechanical/electrical equipment you use

**ON THE JOB, HOW SATISFIED ARE YOU WITH THE SAFETY MEASURES AGAINST?**

- Falling, tripping, or slipping
- Physical injury by equipment and objects
- Radiation
- Intense light or flash
- Loud noise
- Smoke
- Other (specify)


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Vita Auctoris

Sandra Gail Chisvin

Date & Place of Birth: July 20, 1959, Toronto, Ontario, Canada

Marital Status: Married November, 1983, Toronto, Ontario, Canada (married name: Feldstein)

Education: 1983 Master of Human Kinetics (M.H.K.), University of Windsor, Ontario, Canada

1981 Bachelor of Science (B.Sc.), University of Guelph, Ontario, Canada

Awards: 1983 Graduate Research Scholarship, University of Windsor, Ontario, Canada

Professional Affiliations: Ontario Association of Applied Kinesiologists, Charter Member

Canadian Society for Biomechanics

Human Factors Association of Canada