Health Aspects of Work With Visual Display Terminals

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Visual display terminals (VDTs) are in widespread and continuously increasing use by a large number of people. Several physical factors may affect an operator’s performance and health. These include visual factors such as display characteristics, image quality, resolution, stability, color, polarity, illumination, and contrast, as well as lighting conditions and indoor climate. Work station design and layout play the most critical role in eliminating sources of postural problems. Exposure of the operators to various radiations that may be produced by VDTs is not expected to have any health implications, as the levels of emissions are very low. Musculoskeletal effects and visual fatigue can usually be successfully controlled through proper design and use of work stations.

Visual display terminals (VDTs) in their simplest form, as cathode ray tubes (CRTs), have been in use for a long time. The recent revolution in computer technology has brought the VDT into everyday use by tens of million of workers. Concerns have been expressed by workers about the possible adverse effects of VDTs on their health. The range of conditions alleged to be caused by the VDT is broad but can be narrowed to a few general areas. Although some of the health effects are well documented, other allegations are without substantiation. Not infrequently, the adverse health effects of work on VDTs have been overreported and misinterpreted.

Because of these problems, the World Health Organization (WHO) Regional Office for Europe requested the WHO Collaborating Centre at Health and Welfare Canada to prepare a draft document that reviewed and discussed the various health-related aspects of the use of VDTs. A number of experts (Appendix 1) commented on the draft document. The regional office then convened a group of experts (Appendix 2) in Geneva, Switzerland, from May 21 to May 23, 1986, to review, discuss, and finalize this document, also giving consideration to the written comments received. Dr. M. A. Stuchly acted as Chairman, Dr. C. MacKay and Dr. F. S. Barnes as Rapporteurs, and Dr. M. J. Suss as Scientific Secretary.

Physical and Psychological Factors

Health scientists recognize the existence of both physical and psychological influences on workers’ health. The purpose of this review is to provide, as completely and objectively as possible, guidance on those health aspects of work with VDTs that are due to physical factors. No attempt, however, has been made to give a comprehensive critical evaluation of all the numerous scientific and other publications on the subject. In arriving at conclusions, only those publications that contain results of well-performed studies are relied on. Preference was given to publications in refereed journals and technical reports, mostly prepared by various government organizations. A more detailed review of VDT issues was recently published by Bergqvist,1 and many topics were addressed at a recent conference.2 Although this review concentrates on the physical aspects, these are, in many ways, inseparable from the psychological aspects. There is evidence that the number of symptoms and complaints about VDTs is related inversely to the degree of job satisfaction, a not altogether surprising conclusion. The difficulty of isolating the degree of physical causation from the confounding effect of psychosocial elements is acknowledged, and it is unlikely that the two can be separated totally in the
near future. Nonetheless, the degrees to which the real physical problems exist are strongly dependent on the work environment and the intensity and duration of use of the equipment.

Visual Factors

Workers and workers’ organizations have expressed concern for some years about possibly harmful effects of VDTs on the eyes. A critical review concluded that recent prospective studies have not indicated elevated rates of ocular pathology in VDT users when compared with that of nonusers of VDTs. However a number of surveys have reported a high incidence of eye complaints. Various symptoms have been described and reported, the most common being “eyestrain,” more properly called visual fatigue. However, eyestrain is not recognized by ophthalmologists as a clinical condition. Duke-Elder and Abrams, quoted by the National Research Council9 regard visual fatigue as a number of symptoms that may be classified as visual (especially blurring), ocular (the eyes feel tired, hot, uncomfortable, or painful), referral (e.g., headaches) and functional (behavioral). The causes may be environmental, ocular, or constitutional. There is evidence that visual acuity plays a comparatively minor part in the generation of symptoms. The environmental causes (illumination, the visual task, and the characteristics of the objects viewed) and to some extent the ocular causes (visual status) are considered below. The causes of visual complaints may be considered as arising from the VDT itself, the indoor lighting conditions, or the operator’s vision.

The requirements for easy reading (which is the basic visual demand) can be expressed simply as follows: The reader must have good eyesight (corrected if necessary); the object must be clearly visible; and distracting influences must be at a minimum. The discussion that follows is concerned principally with questions of legibility and readability.

Visual Display

Display Characteristics

This review is limited to VDTs based on cathode ray tubes (CRTs), even though other forms of display exist (e.g., plasma, liquid crystal, electroluminescence) and may become more popular in the future. For practical purposes, all α-numeric characters are assumed to be displayed in a dot-matrix form on a CRT. The display may exist in one of two polarity modes: light characters against a dark background (negative contrast) or dark characters against a light background (positive contrast). In some terminals, textual material may be shown in one polarity mode while information to the operator is shown in the other.

Image Quality

The factors that ensure good visibility of individual characters or the whole text on a VDT display have been discussed in detail elsewhere.9 The principal manufacturers of currently available VDT models have taken these factors into account in their designs. The visual comfort of the VDT user depends not only on the quality of the product but also on the environment of the workplace. Certain characteristics of the VDT display interact with environmental conditions in such a way that serious attention must also be paid to the latter.

Modern VDT displays are designed so as to enable them to be read as easily as possible. The principal characteristics of VDTs that affect the image quality are resolution, display stability, color, display polarity, luminance, and contrast.

Resolution

The image on the screen is produced by the impact of a beam of electrons on the phosphor which coats the inner surface of the screen, thus causing the phosphor to glow for a short time. The α-numeric display is made up of the elements of a dot matrix. It is now generally agreed that for the Roman alphabet, a 7 × 9 matrix (i.e., one with seven-dot rows and nine-dot columns) is the lowest density that should be used. For adequate resolution, upper-case characters should subtend an angle of 15 to 21 minutes of arc to the eye, with the higher figure preferred. The mean, i.e., 18 minutes of arc, results in a character height of about 2.6 mm at a viewing distance of 0.5 m or 3.6 mm at a viewing distance of 0.7 m. International standardization of these parameters is currently under way. Character spacing, line spacing, and other similar details are also important.8

So far nothing has been considered that might not apply to the printed page. However, the image on the VDT screen is produced by a beam of electrons that activates a phosphor and produces an image made from glowing light. Furthermore, this image is produced on the back side of the thick, curved, glass base of the CRT, which raises questions relating to brightness, contrast, flicker, color, and reflections.

Display Stability

On electronically generated displays, legibility and comfort can be substantially influenced by the stability of the image, which is affected by flicker and other less common forms of instability. The latter include the apparent tendency for characters to periodically jump or “jitter” and a slow, rhythmic, wavering effect known as “swim.” The appearance of flicker on VDT screens is dependent upon relevant design characteristics of the display and upon personal factors of the individual user. The former include phosphor type and regeneration rate; character luminance, size, and color; area of screen illuminated; and viewing angle. The latter include large individual differences in both the threshold at which flicker is perceived and sensitivity to it, both in terms of annoyance and distractibility. Notwithstanding its interaction with other display parameters, refresh rate

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is an important determinant of flicker perception. Older VDTs have rates of 60 Hz in Europe and 60 Hz in North America, but more modern VDTs have regeneration frequencies somewhat in excess of these (typically 70 Hz). However, a few persons may still be able to detect flicker. For positive contrast displays, a refresh rate of 100 Hz has been recommended to eliminate the problem of flicker caused by the higher luminance in this mode of presentation.

Color

There is general agreement in the published literature that the color of the display, which depends either on the particular phosphor or on a color filter, has little, if any, effect on legibility. Use of colors at the blue or red ends of the spectrum would make the image less distinct, owing to the chromatic aberration of the eye. At present, these colors are used only for specialized applications.

Display Polarity

Traditionally, VDTs used a negative mode of text presentation (bright characters on a dark background). More recently, positive contrast displays (dark characters on a bright background) have become more common. Both approaches are acceptable, provided the requirements for luminance, contrast, and resolution are met. The positive contrast mode minimizes the effect of reflections on the operator’s screen, appears similar to the traditional typescript page, and may allow less stringent ambient illumination. However, as has been noted, there is a requirement for higher frequency refresh rates for flicker-free viewing.

Luminance and Contrast

The legibility of information displayed electronically on the screen (as expressed in terms of human performance) and ease of perception (a determinant of comfortable viewing) are markedly affected by the contrast between the characters and the background (one being brighter than the other, depending upon polarity). Contrast is also affected by ambient lighting conditions and reflectivity of the screen. Consensus is that either the character or its background, whichever is brighter, should achieve a minimum level of between 35 and 45 candela/m². Under acceptable ambient conditions, a contrast ratio of about 3:1 or 4:1 is acceptable. The operator should have some form of control over one or more of these parameters in order to achieve a preferred level. This is usually achieved by the brightness control which, in the case of negative contrast displays, modifies the contrast between character and background by changing character luminance.

Hard Copy Quality

Another visual task performed by many operators, especially those engaged in word processing and data entry, is the reading of printed or written material. This material may often be of poor quality and legibility, and may arise from carbon copies, telex copies, handwritten texts, or output of poor-quality printers. Paper quality is important, too, and the use of glossy paper can, under certain lighting conditions, result in an image that is extremely difficult to read.

Lighting Conditions

Reflections

Perhaps the most common and most serious factor degrading image quality arises not from the design characteristics of the individual CRT but from reflections due to light sources external to the equipment. Such sources include, for example, luminaires, inadequately shielded task lighting from adjacent desks, windows, and even the operator’s own clothing, particularly if it is light-colored and the ambient light level is comparatively high. Reflections may be either diffuse or specular, and the latter will appear to the operator to be located at a point behind the screen. This may give rise to accommodation problems if the operator is subconsciously attempting to look both at the screen characters and the reflection. All reflections affect the apparent contrast between the alphanumeric characters and their background, and they may limit it to such an extent as to make the display unreadable. This effect is well known to anyone who has attempted to watch television in a brightly sunlit room.

Reflections are best avoided by controlling their sources. Luminaires and task lights should be suitably shielded, windows should be obscured with venetian blinds, window shades, or drapery. Overall illumination should not be too high. However, if all sources of reflections cannot be eliminated, an attempt should be made to eliminate their effect on the VDT by other means. One method is to provide a hood to shade the screen from the source(s) causing the reflection. This method may interfere with the task if the hood must be extended for some distance in front of the screen. A second method is to reduce reflections either by treating the glass or by using an antireflection filter. In a majority of modern VDT displays, low reflectivity is achieved by special coatings or meshes on, or etching of, the glass surface. However, no method of surface treatment or filtration added after manufacture is yet satisfactory enough to be recommended for use. Most methods degrade the luminance of the display and impair character resolution and thus may add to eye fatigue. Questions of cost and filter life also are important. The original proposition, that the best way to deal with screen reflections is by eliminating the source, remains unchallenged.

An irritating source of visual discomfort may arise from the keyboard. Keys are generally made with concave surfaces, but if they have a shiny finish, and particularly when they are dark in color, each one can be a source of specular reflection, especially when a light source is directly, or almost directly, overhead.
This may not affect expert operators, who seldom look at the keys, but many VDT users do not have this degree of skill. A person who is not fully familiar with the keyboard will need to identify many keys by sight, and this can be difficult under the adverse circumstances mentioned above. Keys, therefore, should be matte-surfaced, and preferably have dark characters against a light background.

Glare

Glare is defined as the sensation produced by luminances within the visual field that are sufficiently greater than the luminance to which the eyes are adapted to cause annoyance, discomfort, or reduction in visual performance and in visibility. Glare can also be defined as a visual condition that occurs when the range of luminances in the visual field is too great, with the result that the processes of visual adaptation are disturbed. Apart from screen glare arising from reflections, the principal sources of glare that will affect a VDT operator are windows, walls, luminaires, and task lighting of source documents. Operators should not sit facing bright windows. Either the windows should be shaded with curtains or blinds or the operator should sit at right angles to the window (to sit with one's back to the window merely invites further reflections). Wall should have a matte surface and only a moderate degree of reflectance, as should desk tops. Luminaires in many offices often consist of groups of fluorescent tubes above a sheet of plastic material, flush with the ceiling, which diffuses the light and provides relatively even illumination. However, luminaires of this kind are significant sources of glare and their use should be avoided whenever possible. A number of other types of fixture are available that do not cause glare owing to their shielding the operator from light directed sideways from the light sources.

Workplace Lighting

Ambient lighting in work areas where VDTs are used should be somewhat less bright than is normally recommended for general office work. However, the recommendations concerning both general office lighting and general lighting for VDT work are so varied that it is difficult to come to a firm conclusion. For instance, standards for typing vary from 480 to 1,615 lux, with an average of 766 lux. A number of recommendations for VDT general lighting have been made, varying from 50 to 750 lux, with 300 lux being perhaps the median figure. This median is the level of illumination at which the display can be seen clearly and which is adequate for most other tasks the operator performs, but it may not be adequate for reading source documents. In such a case, the documents should be lit by a separate lamp, shielded to eliminate specular reflection for other workers, and with a dimmer control so that the operator can adjust the degree of illumination of the document. Newer forms of display, however, allow higher illuminance levels. Similarly, newer forms of indirect lighting are capable of improving the quality of illumination in VDT installations.

Operator's Vision

Even if the display is well designed and the lighting conditions are optimal, the operator may still not see properly. The ability to see clearly depends upon a number of factors. They include visual acuity, or the ability to resolve objects in close proximity to each other; accommodation, or the ability to bring objects into focus at varying distances; and, to a lesser extent, muscle balance or the ability to direct both eyes simultaneously at the same object.

Visual Acuity

Smith et al. failed to find any meaningful relationship between adequacy of refraction and reporting of work-associated symptoms. However, this somewhat surprising finding would require much more extensive and detailed investigation before one could confirm and disprove totally any relationship between visual acuity and either performance or symptoms. Cakir et al. state that a large proportion of the general population does not have adequately corrected vision. This includes both those who have never had their vision corrected and those whose previous corrections are no longer appropriate. Although some workers who use VDTs may have little or no problem even with a less-than-optimal correction of their visual acuity, such a comparatively simple measure should be carried out before the cause of symptoms is sought elsewhere.

Accommodation

The use of the VDT will spread to more and more segments of the population, including many persons more than 40 years of age, which is about the age at which most people who have hitherto been proud of their "perfect" eyesight begin to have problems. This is chiefly due to loss of the power of accommodation, ie, the ability of the lens of the eye to change shape enough to bring near objects into focus. This defect can be corrected by suitable spectacles, but such a correction may severely limit the ability to focus on distant objects. For example, the same lens may allow objects to be seen clearly at 0.2 m but not beyond 0.4 m. This explains why some persons who find their spectacles excellent for normal reading distances cannot focus clearly on a VDT screen, which is liable to be 0.5 m or more from the eyes. Users of bifocal spectacles may, therefore, find that the upper part of the lens, adjusted for distant vision, will not allow them to focus down to the 0.5 to 0.7-m range that they need to use, whereas the lower part of the lens, though comfortable at ordinary reading
distances, is inadequate for the 0.5 m demanded at the work station. Alternatives such as the use of trifocal or progressive addition lenses are often unsatisfactory. Some VDT users may need a lens prescribed for the VDT working distance. Other conditions of the eye may also affect the ability to see the screen clearly, chief among which are the phorias or eye muscle imbalances. Within limits, these may be compensated for by subconscious muscular effort. However, this may result in a degree of unacceptable muscular fatigue. Adequate correction by lenses is often possible.

Work station design may in many instances alleviate the problems that arise from accommodation problems.

Indoor Climate

Temperature

Although ambient temperature requirements for VDT operators do not differ in any way from those of other office workers, the VDT itself may be a significant source of heat. The heat generated by a VDT is usually in the range of 100 to 400 W compared with 35 to 50 W from an electric typewriter and about 100 W from a human body. Thermal loading of a working environment with VDTs may be 80% to 150% greater than that without VDTs. This depends on a number of variables, such as the type of VDT in use, the number and density of VDTs in a given area, and the capability of the air-handling system. Some account must be taken of thermal load before VDTs are introduced into a workplace, and engineering advice should be sought.

Relative Humidity

Relative humidity does not appear to warrant much attention. Relative humidity levels above 60% have been proposed. However, such elevated levels may cause material damage to buildings. The minimum level accepted in North America is 20%, perhaps due to window condensation problems encountered in extremely cold weather. However, wherever possible, a relative humidity of at least 30% and preferably higher should be maintained when VDTs are in use. Furthermore, higher humidity eliminates electrostatic charge accumulation, which might be responsible for skin rashes.

Noise

The VDT itself is remarkably quiet, with only a faint sound coming from the keyboard. Older models of printer are noisier, but acoustic shielding can reduce this noise to a low level. The question of ultrasonic vibrations is considered in the section on radiation emissions.

Nevertheless, some VDT operators find noise a problem in the working environment. Sounds at pressures well below those capable of producing temporary thresh-

old shift can nevertheless be sources of distraction or can even interfere with mental concentration. Here it is the quality or character of these sounds, rather than their intensity, that is of importance. Because each individual situation will have its own characteristics it is not possible to make specific recommendations. It is the job of supervisors to investigate individual complaints and to effect the necessary cures.

Work Station Design and Layout

Operator Posture

When discussing work station design, the question should be asked: "What kind of work and for how long?" The VDT is only a tool, and the work station must be designed around the kind of work the user is doing. Even constant users of VDTs, such as airline-counter clerks, may need the space immediately in front of them for writing (e.g., making out tickets or baggage checks) and they may also, in some locations, have to load baggage onto conveyors. Their work stations must, therefore, be designed with these other tasks in mind, even though the VDT may be used for processing each passenger.

It is generally found to be most convenient to start with the full-time user in mind, such as the work processing operator. In this work the tasks include keying in information accurately and rapidly (using hard copy of varying quality), laying out the text, proofreading and editing, making changes to earlier drafts and finally, operating a printer. Different kinds of paper, or perhaps forms, may be needed and reference material may need to be consulted. In addition, the equipment itself must be considered. Flat-screen presentations are still rare, so one must contend with a CRT that, with its associated components, is both bulky and heavy. Attached, but not fixed to it is the keyboard, which in most cases is much wider than a typewriter keyboard. There may also be a disc drive, set either on or below the desk, a printer and perhaps a modem. With all this equipment, the operator requires much more space—more floor area and probably more desk surface—than a typist doing comparable work.

The relative positioning of the display, keyboard, and document holder should be determined by the user's task. Large work spaces and adjustable equipment allow task requirements or personal preferences to be accommodated.

The work space should be built around the seated operator. Until recently, the correct position for sitting in front of a keyboard was considered one in which ankles, knees, hips, and elbows were all at more or less right angles, with thighs and forearms parallel to the floor.5 This convention has been challenged more recently in the case of school children and others whose work consists principally of reading and writing12 and also in the case of VDT operators.11,12 Personal observation of a limited number of word-processing operators tends to confirm the impression that, even with adjust-
able furniture, they do not necessarily prefer the "conventional" seated position. Studies have shown that the use of adjustable furniture can lead to a decrease in the number of musculoskeletal complaints but that a preferred posture is unlikely to be well defined. Further studies are necessary before firm conclusions can be reached. Research on this topic should carry a high priority because of its potential impact on furniture design, particularly that of the chair.

Whatever position may be found most comfortable by operators, certain fundamentals remain. The feet must be firmly and comfortably supported, either on the floor or on a foot rest, and there must be ample room to move the legs. The thighs, again, must be supported, but the front edge of the chair must not exert pressure on the popliteal area and is therefore best curved downwards. The seat itself should be suitably padded and shaped. The back must be properly supported. This implies a degree of curvature of the back rest to support the lumbar region, but equally important is that the back rest be high enough to provide support at least up to the angles of the acromial. The hands should be comfortable, too. Grandjean et al found that the mean preferred elbow angle among their subjects was 99 degrees, and Cakir et al recommend an elbow angle of 90 degrees or more. An angle of 30 degrees of forward inclination of the head is usually suggested. One further matter of importance is the viewing distance. As discussed in the section on vision, it should be not less than 0.45 m and not more than 0.7 m, depending on character size.

Keyboard and Terminal Adjustments

A separate keyboard and an adjustable orientation of the screen are desirable. Although in some instances a fixed keyboard may be preferred or can be tolerated because of limited use, a separate keyboard is essential for most operators. The reason is that for any given person and any given preferred seating position, the existence of a fixed keyboard dictates the distance from the eyes to the display screen and also the inclination of the head, i.e., the viewing angle. The only way in which these two can be changed is by adopting a less comfortable position. However, if the position of the keyboard relative to the display screen is not fixed, an optimal distance can be achieved from the eyes to the screen and a difference, although not necessarily optimal, viewing angle. Such an angle can only be guaranteed if the height and angle of the display screen can also be adjusted. A stand that also allows a degree of forward and backward tilt and rotation in the horizontal plane helps to eliminate reflections and will aid user comfort and performance.

Work Station

Given the above requirements, one is faced with the problem of how to satisfy them when dealing with a population ranging from small women to tall men. The range of dimensions is considerable and, therefore, a degree of adjustability of furniture is essential. Several authors have made specific recommendations on furniture dimensions, and a summary of the major recommendations can be found elsewhere. Certain basic principles applicable to the chair, footrest, and desk will be discussed here.

The chair is the most important item involved. It is possible to improvise to some extent with regard to other items, but not with a chair. Its range of adjustments should cover seat height, seat tilt, and backrest height and tilt. A chair should have five legs, and if equipped with wheels, there should be sufficient friction to maintain a stable position. Armrests are generally not desirable, but if provided, they should be adjustable for height and easily detachable. All adjustments should be capable of being made from the seated position without the use of tools and with a minimal degree of physical effort.

The footrest should be adjustable over an adequate range of height and angle, and should be wide enough to allow shifting of the feet for purposes of comfort. Its upper and lower surfaces must provide enough friction so that the feet do not slip on the footrest and that the footrest does not slip on the floor.

The desk or table must allow the keyboard to be low enough for the hands to rest comfortably but not so low as to intrude on the space required by the thighs. On the other hand, the CRT must be high enough to allow the line of sight to intersect the middle of the screen at the proper working distance with the head held at a comfortable angle. If reference material has to be consulted, it must be easily accessible.

This challenge to the furniture engineer has been met in various ways. At least 50 models of tables are available in Europe. The most commercially successful models have one platform supporting the display screen and another supporting the keyboard, with the height of each being independently adjustable. One or both platforms may be moved forward and back. In the models that we have observed, the adjustments of height may be set either manually or by electric motor. Considerable ingenuity is required in designing a hand-cranked platform that can be easily operated, particularly the rear platform which carries by far the greatest weight. Tables used by a number of operators should be quickly adjustable to a range of heights. Adjustments, if provided, must be capable of being made quickly and easily by the operator from seated position and without the use of tools.

Wrist supports have been suggested by a number of authors. Grandjean et al found that forearm or wrist supports, when provided in their experimental work stations, were used by 80% of subjects and were disliked by only 3%.

The document holder is a feature which is sometimes neglected. The holder does not need to be complicated in design, but it must be adjustable so that the hard copy is at the same height as the screen, close to the screen (to avoid gross head movements), at the same
distance from the eyes as the screen itself, and at right angles to the line of vision.

Adjustable work stations are expensive. Cakir et al. have appraised the physiologic and cost advantages and disadvantages of various combinations of fixed or variable heights of desk, seating, and footrest. Their conclusions are that control over all three parameters is physiologically desirable but very costly. The combination of variable desk and seating height with fixed footrest height is judged to be physiologically very good but uneconomical. The combination of fixed desk height with variable seating and footrest height is appraised as physiologically satisfactory and the most economical.

Other alternatives are available when funds are limited. For instance, a ledge can be installed against the front edge of a normal desk and at a comfortable distance below its surface that will hold the keyboard and will improve comfort for most operators, even though it may still fall short of the ideal. The CRT terminal may be raised on a specially designed stand so that it more nearly approaches a satisfactory working height. Footrests that are not adjustable for height will not be ideal, but again they may help in what, on occasion, will be inevitable compromises between operator comfort and financial constraints.

Fig. 1 shows an example of the actual situation. It illustrates a number of the points that have been made in the text, namely:

1. Although the equipment in question is of comparatively early design it is remarkable, nevertheless, that the designer kept the screen so low that its center is only 0.1 m above the home row of the keyboard. The operator happens to be taller (about 1.75 m) than the average woman but to allow her forearms to rest at a comfortable angle, she has raised the seat to its maximum height. In consequence her angle of vision to the center of the screen is about 45° below the horizontal. Her normal use of the equipment averages perhaps one hour a day, but when circumstances necessitate that she uses it for virtually the whole working day she confesses to considerable discomfort not only in her back but also in her neck. One can assume that a full-time operator would complain of severe back and neck pains occurring daily.

2. Although the screen is tilted backwards about 19 degrees, it is still too low for this particular operator. To achieve a forward head inclination of 20 degrees (which is generally recommended), the screen would have to be raised at least 0.3 m, and in this particular case a major redesign of the equipment would become inevitable. The other alternative would be to lower the sitting height by some 0.25 m, with its consequent effects upon leg comfort.

3. The chair is obviously closer to state-of-the-art design than the electronic equipment. Its back reaches higher than what used to be regarded as suitable for typists' chairs, and the seated height is adjustable with minimum effort. Its five legs give about 14% greater stability than a similar four-legged chair and yet allow enough foot room between the legs.

In view of what has already been stated concerning the wide range of preferred position on the part of operator, an "optimum" seated position is not illustrated. Furniture design should allow the maximum of adjustability about already known human dimensions.

Radiation Emissions and Fields

In this section a brief description is given of the various types and sources of radiation emitted by VDTs. Results of surveys conducted in many countries on radiation emissions are summarized, and the levels of exposure are compared with those recommended by various national and international standards or, where such standards do not exist, with the available scientific data on health hazards of exposure to these radiations. No attempt has been made to review the biologic effects of the various radiations, but references to published reviews are cited and some contentious issues are briefly discussed.

Radiation may be defined as the propagation of energy in a physical system. Two types of radiation are associated with VDTs: electromagnetic radiation and acoustic radiation. Electromagnetic radiation encompasses a wide range of frequencies (Fig. 2). There are two types of electromagnetic radiation: ionizing (which is most frequently associated with the term "radiation") and
Nonionizing. In the case of ionizing radiation, a single photon can ionize an atom or a molecule. In the case of nonionizing radiation, the photon energy is not sufficient to ionize the atom or molecule in a single step but may do so at very high levels of radiation through multiplet-step processes. Usually, this type of radiation does not ionize matter but interacts with biologic systems by other mechanisms such as heating and field forces. As can be seen from Fig. 2, nonionizing radiation covers a wide range of frequencies, and various mechanisms in different frequency ranges are responsible for interactions with biologic systems.

Acoustic radiation in this context refers to the propagation of sound and ultrasound.

Radiation Sources

The potential sources of radiation are the CRT, which may produce x-rays, ultraviolet, optical and infrared radiations, and the horizontal deflection system, coils, transformers, and other electronic circuitry, which may produce emissions at extremely low frequencies (ELF) and at radio frequencies (RF). Fig. 3 schematically illustrates various sources of radiation within a VDT. Audible sound and ultrasonic emissions can be produced by the flyback transformer in the horizontal deflection system.

X-ray Emissions

VDTs usually operate at a relatively low CRT voltage (about 13 kV) for monochrome terminals, and up to about 25 kV for color terminals), and x-ray produced are absorbed by the glass of the CRT. Under these conditions, x-ray emissions are well below the natural background. Furthermore, designs of modern VDTs are such that a significant increase of the CRT voltage, which would result in an increased production of x-rays, is very unlikely. In monochrome CRTs, the display becomes unusable at about 15 kV. In color CRTs (eg, those used in color television (TV) sets), higher voltages are used, control circuitry is employed which causes the VDT to cease operation when the CRT voltage exceeds a set level.

Some countries (eg, the USA, Canada, and the Federal Republic of Germany) have government regulations for TV receivers and/or VDTs. These regulations specify a limit for permissible x-ray emissions.16,16

Visual Display Terminals/Marriott et al
A large-scale study of x-ray radiation from VDTs and TV receivers performed in the USA, indicated that the emissions under normal and severe test conditions are 96 nanocoulombs per kilogram per hour (nc/kg h) (1 nC/kg 8.876 nR [nanorontgen]). 36 nC/kg/0.1 mR/hour or less.\textsuperscript{15} Numerous tests of VDTs in use showed that x-ray emissions were below the natural background, i.e. about 2.6 nC/kg.\textsuperscript{16-19} In a few cases, reports of excessive levels of x-rays were found after investigation to have been the result of faulty measurements.\textsuperscript{16,17} Some models of color TV monitors, which in premarket testing under severe overload conditions were found to produce x-rays above 129 nC/kg, were not allowed onto the market.\textsuperscript{17} Finally, tests performed on nearly 70 different models in a low-background facility with extremely low background radiation showed that x-ray emissions were less than $7.7 \times 10^{-6}$ nC/kg. This was the background level in the test facility employed, and it can be considered extremely low (approximately one thousandth of the normal background). No x-rays could be attributed to operation of the VDT because the measured radiation levels were the same whether or not power to the test VDT was switched on or off.\textsuperscript{20}

In view of these results, the conclusions and recommendations of various government agencies\textsuperscript{16} are well justified. The main conclusion is that x-ray emissions from VDTs are either nonexistent or so low that they do not pose a health hazard either to the operator or to a fetus. Furthermore, there is no need for periodic testing for x-ray emissions of VDTs whose models meet appropriate government regulations, inasmuch as there is nothing inherent in VDT design or operation that can cause the production of x-rays with aging of the equipment. Consequently, the use of lead or other protective aprons is entirely unnecessary.

Ultraviolet Optical and Infrared Radiation

Measurements of emissions from VDTs in these parts of the electromagnetic spectrum have been reported.\textsuperscript{17-19,31-37} Representative data are summarized in Table 1 and are compared with the limits recommended in the USA.\textsuperscript{38} Similar exposure limits are recommended in other countries. This comparison indicates that ultraviolet, optical, and infrared emissions from VDTs are about 100 or more times below the recommended limits.

Radiofrequency Radiation

Radiofrequency (RF) fields are characterized by the electric and magnetic fields. Extensive measurements in the frequency range of 10 kHz to 10 GHz have indicated that the main sources of emission are the flyback transformer and the horizontal deflection coil, which are parts of the electronic circuitry responsible for moving the electron beam horizontally on the screen. This movement usually occurs at a frequency between 15 and 22 kHz. In some VDTs the main source of emissions is the high-voltage secondary wiring.

Because of the complex waveform of the scanning signal, up to ten harmonics of the fundamental frequency house of 15 to 50 kHz are present.\textsuperscript{18,39-40} Outside this frequency range, the emissions are very low. Some emissions may be present at the frequencies of digital clocks and other digital circuits. Their range is 3 to 300 MHz, and the electric field strength is below 0.2 V/m at the VDT surface.\textsuperscript{18,21,30}

RF fields around VDTs at frequencies between 15 kHz and 250 kHz are very low for many models. Various measurements show that some VDT models produce measurable emissions.\textsuperscript{15,21,35-37} A small-scale statistical sampling showed that in only about 85% of VDT models was the electric field strength in excess of 1 V/m at the operator's position.\textsuperscript{15,21} None of the measured emissions results in hazardous exposures.

Table 2 summarizes the available data on maximum strengths of the electric and magnetic fields (root mean square [rms] values) at the operator's position. This position was defined in a conservative manner as 0.8 m from eyes to screen. Field strengths decrease with distance from the screen. At 0.3 m from the screen, the maximum electric field strength was 15 V/m and the maximum magnetic field strength was 0.17 A/m. These maximum values were obtained after testing 505 different models of VDTs; therefore they can be considered representative. Some older models may produce stronger fields. Additionally, the rate of change of the magnetic field is up to 400 (milliteles per second) (mT/s) depending on the model.\textsuperscript{38}

<table>
<thead>
<tr>
<th>Reference No.</th>
<th>No. of VDT Models (Units)</th>
<th>UV A (W/m²)</th>
<th>Visible Radiations - A (W/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
<td>38 (28)</td>
<td>12.9 x 10⁻³</td>
<td>7.5</td>
</tr>
<tr>
<td>17</td>
<td>4 (22)</td>
<td>0.2 x 10⁻²</td>
<td>71</td>
</tr>
<tr>
<td>18</td>
<td>16 (136)</td>
<td>8.5 x 10⁻³</td>
<td>137</td>
</tr>
<tr>
<td>26</td>
<td>14 (14)</td>
<td>2.5 x 10⁻³</td>
<td>10</td>
</tr>
<tr>
<td>21</td>
<td>1 (1)</td>
<td>0.2 x 10⁻²</td>
<td>100</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Reference No.</th>
<th>No. of Models (Units)</th>
<th>E (V/m)</th>
<th>H (A/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>26</td>
<td>14 (14)</td>
<td>2.7</td>
<td>-0.08</td>
</tr>
<tr>
<td>24</td>
<td>38 (38)</td>
<td>15</td>
<td>-0.08</td>
</tr>
<tr>
<td>15</td>
<td>3 (3)</td>
<td>2.4</td>
<td>0.04</td>
</tr>
<tr>
<td>18</td>
<td>57 (96)</td>
<td>4.4</td>
<td></td>
</tr>
<tr>
<td>Stuchly, personal communication</td>
<td>17 (43)</td>
<td>7</td>
<td>0.09</td>
</tr>
<tr>
<td>32</td>
<td>44 (44)</td>
<td>0.17</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>3 (3)</td>
<td>3.5</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>27 (24)</td>
<td>2.6</td>
<td>0.16</td>
</tr>
</tbody>
</table>

*Estimated value from the reported 35 V/m. The scaling method recommended by the author was used.\textsuperscript{38}
At a distance of 0.3 m from the VDT surface, close to the location of the flyback transformer or other source of emission, the maxima of the field strengths may reach 50 V/m and 1.1 A/m for the electric and magnetic fields, respectively\(^{56}\) (M. A. Stuchly, personal communication, 1985); values of 16 V/m and 0.5 A/m are more typical.\(^{24,30}\) These fields are localized. Still higher field strengths have been found near the VDT surface, but the accuracy of measurement of these fields is suspect.\(^{16}\)

Recommended limits of exposure to RF fields are summarized in Table 3. A comparison of the reported VDT operator exposures with these limits leads to the conclusion that unless the operator is within 1 m from the side or the back of another VDT which happens to produce high emissions, even the highest exposures are within the most stringent standards for the general population. In nearly 65% of cases, exposures are below these limits by a factor of 10 (ie, the electric field strength is below 1.5 V/m). Some VDTs produce higher field strengths at the side or the back; to maintain low levels of operator exposure to RF fields, it is a good practice to site VDT operators at sufficient distances from the side and/or the back of adjacent VDTs. This recommendation does not apply if the adjacent VDTs are known to emit only very low level RF radiation (eg, at 0.3 m the electric field strength is not more than 10 V/m).

Considerable discussion of possible health effects of exposure to RF fields from VDTs has recently ensued following research reports on the biologic effects of weak electromagnetic fields.\(^{33}\) In the last few years, weak electromagnetic fields have been shown capable of interacting with biologic systems at specific frequencies and intensities.\(^{33,35}\) Both the electric and the magnetic fields appear to be capable of such interactions, but their mechanisms are not known. The effects reported occur, however, at carrier and modulation frequencies between 1 and 1000 Hz. Suggestions have been made that the waveform of the fields and, in particular, the rate of change of the magnetic field may be important in inducing biologic effects. These suggestions followed an uncorroborated study of the teratology of chick embryos\(^{58}\) and can only be considered as an interesting hypothesis yet to be scientifically confirmed.

When exposure of the VDT operator is compared with available scientific data on health effects of RF fields and recommended exposure limits, it is very unlikely that these fields have any health significance.

### Extremely Low Frequencies (ELF)

VDTs, like any other electrical or electronic device, produce stray electric and magnetic fields at power-line frequencies (50 or 60 Hz) and its harmonics. Measurements of the electric field strength up to 10 V/m (rms) and magnetic field strengths up to 0.22 A/m and 0.56 A/m (rms) have been reported.\(^{29,30,37}\) Only a few VDT models have been tested.

The ELF fields around VDTs are not much different from ambient levels in laboratories and homes (typically 1 to 10 V/m and 0.01 to 1 A/m), and they are weaker than the fields around other electrical devices such as household appliances, which reach 250 V/m and 23 A/m at a distance of 0.3 m.\(^{30,37}\)

There is substantial scientific evidence that much higher ELF field strengths than those associated with VDTs are required to cause potentially hazardous biologic effects.\(^{37,38}\) Some evidence has recently emerged that fields of strengths comparable to those in some ambient environments and around VDTs can produce biologic effects under certain conditions.\(^{38,34}\) Most of these effects, but not all, are quite subtle and not necessarily hazardous. Furthermore, the effects observed occurred only under very specific conditions in animals. For instance, Delgado et al\(^{26}\) and Ubeda et al\(^{29}\) reported that weak magnetic fields produced teratogenic effects in chick embryos. Although one or two parameters of the exposure fields employed in these studies are similar to those around VDTs, there are significant differences in numerous other parameters. Any extrapolation of these study results to exposure of VDT operators can only be considered tenuous.

Biologic effects of weak ELF fields are important from the point of view of basic science and medical applications, and they certainly warrant further research. However, their significance from the viewpoint of health protection is less obvious. At this time, these interactions do not seem likely to affect human health. However, should this conclusion prove incorrect, the outcome applies not only to VDTs but to all electrical and electronic appliances and devices, as well as to systems that distribute electricity.

### Electrostatic Fields

A quasistatic (varying very slowly with time) electric field is produced by the electric charge on the CRT screen.\(^{28}\) The strength of this field decreases rapidly with distance from the screen. The charge on the CRT

<table>
<thead>
<tr>
<th>Reference</th>
<th>Frequency Range (kHz)</th>
<th>Electric (V/m)</th>
<th>Magnetic (A/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>USSR, general population(^{56,57})</td>
<td>30–300</td>
<td>20</td>
<td>5+</td>
</tr>
<tr>
<td>Czechoslovakia, 8-h exposure, general population(^{33,34})  (WHO)</td>
<td>30–300</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Poland, 8-h exposure(^{33,34})  (World Health Organization)</td>
<td>100–10,000</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>USA occupational(^{26})</td>
<td>10–3,000</td>
<td>600†</td>
<td>1.6</td>
</tr>
<tr>
<td>Federal Republic of Germany occupational and general population(^{37})</td>
<td>10–30</td>
<td>1,500</td>
<td>350</td>
</tr>
<tr>
<td></td>
<td>30–2,000</td>
<td>1,500</td>
<td>350 × 30</td>
</tr>
</tbody>
</table>

* Occupational exposure.
† Depending on the interpretation the level may be higher, as a radiated power output is less than 7 W.
‡ f is the frequency in kHz.
screen depends on display brightness, number of characters on the screen, the rate at which the writing beam is turned on and off and the operating history of the terminal. The design of the terminal and the ambient environmental conditions (e.g., humidity) are also likely to play a role.

Measurement performed on 54 terminals comprising 27 different models showed typical electrostatic field strengths between -150 V/m and +150 V/m, with a maximum of 1500 V/m, at a distance of 0.3 m from the screen.8 whereas another study on 44 VDT models reported electrostatic field strengths from 0 to 30 kV/m at a distance of 0.8 m from the screen.22

The measured strength of the electrostatic field near VDTs can be compared with that of natural environmental fields. At ground level in fair weather, the average electrostatic field is about 100 V/m. The field strength decreases with elevation and at 100 m above ground is about 100 V/m. Local field strengths vary widely, depending on temperature and humidity. Much stronger fields are produced before and during thunderstorms, and field strengths up to 3000 V/m can be observed even in the absence of local lightning.40,41 Furthermore, people can also be charged to a high potential depending on their clothing, floor surface, and ambient conditions.1 Exposure field values of ±10 kV/m around charged persons are not unusual.

Because of strong air resistance, the electrostatic field produces appreciable currents through biologic bodies only when physical contact is made with a charged object producing the field. The static field may produce superficial effects on the skin and may also produce indirect effects through changes in ion balance in air. The available scientific data42 do not indicate that the electrostatic fields produced by VDTs or currents passing through the body when the person touches the VDT can cause harmful biologic effects.

The indirect effects of alterations in air ions are more difficult to assess. First, changes depend not only on the static field produced by the VDT but also on other environmental factors, such as humidity, temperature, air circulation, and other materials and objects in the environment. Second, scientific data on air ions are inconclusive, but current scientific data do not show a significant air ion effect on human physiology at moderate levels.43 Further research is needed on the possible health effects of air ions, which is more likely to be important in other environments than around VDTs. Changes in air ion balance resulting from a VDT are not expected to be large enough to produce biologic effects.

Acoustic Radiation

The source of acoustic radiation in VDTs is the flyback transformer. Depending on their scanning frequency, the emissions are sonic (15 to 20 kHz) or ultrasonic (30 to 32 kHz). Measurements performed on 85 models of VDTs showed that maximum levels at the operator position were from 20 to 68 dB. These levels are below the recommended upper limits of 75 dB or 80 dB.44

Some people are sensitive to lower levels of sound or ultrasound than the recommended limit, but this greater sensitivity does not imply the existence of physiologic damage.45

In most practical situations, acoustic emissions from VDTs contribute relatively little to the noise level in the office environment.46

Other Health Considerations

Abnormal Outcomes of Pregnancy

The popular press has published a number of reports on high rates of miscarriage or birth defect among groups of VDT users. Few of these reports have received detailed investigation, but where this has been done either no cause attributable to VDTs has been found or unusually high rates of such conditions could be expected on the basis of chance alone, particularly in view of the small size of the groups concerned.

A number of epidemiologic studies have since been undertaken, many of which have been criticized on methodologic grounds.47 In a large questionnaire study, the Canadian Labour Congress48 asked two questions relating to adverse outcomes of pregnancy. The replies to these questions indicated that children born to the respondents had a birth defect rate of 3.2 per 1,000 against an expected rate of 4 to 8 per 1,000 for the difference depending on the definition of birth defect) and a spontaneous abortion rate of 140 per 1,000 against an expected rate of 150 to 200 per 1,000. However, the investigator observed that women leaving the labor force after the birth of a child were not included in the survey and stated that "a survey of this type cannot definitely answer whether VDT use is a cause of reproductive problems. A long-term study, following the health patterns of carefully selected samples of workers, can provide more reliable answers."

Recently, Kurppa et al49 analyzed data covering 108 pairs of mothers from the Finnish national register of congenital malformations. All the mothers had worked with VDTs for at least four hours a day during early pregnancy. The analysis led to the conclusion that exposure to VDTs does not cause birth defects.

Källén examined data from official Swedish statistical reports and concluded that there was no evidence that work with VDTs had any effect on rates of miscarriage or infant malformation. The conclusion of this work was that most probably no causal effect existed between VDT operation and the studies on pregnancy outcome.

McDonald et al50 presented preliminary data on the first year of a 2-year study covering about 90% of all women who delivered in the Montreal area and about three-quarters of the women treated for spontaneous abortion in the same area. The study population was selected from five occupational groupings in which at least five % of the women worked with a VDT for 15 or more hours a week, giving a final study sample of 7,692 pregnancies (current and past). Information was ob-
tained by a questionnaire covering both current and past pregnancies. The five occupational groups (professional, clerical, accounting, electronic office machine operator, and reception/telephone) had low overall rates of spontaneous abortions. The rate of spontaneous abortion in 2,609 current pregnancies with no VDT use was 5.7%, in 588 pregnancies with VDT use less than 15 hours a week was 8.3%, and in 710 pregnancies with VDT use of 15 hours a week or more was 9.4%. The same general trend was noted in most of the five occupational groups. For past pregnancies there is no significant relationship between VDT use and the rate of spontaneous abortions. In their interpretation of the data the authors pointed out that selection and response bias could have affected the results, and further analysis is necessary. The possibility that data from current pregnancies are affected by the biases of correlation between the rate of abortions and level of VDT use in the five occupational groups.

There was no statistically significant differences in the rates of congenital defects between nonusers and users of VDTs.

VDT as a Potential Cause

Is there anything inherent in the VDT itself that might make it a cause of spontaneous abortion, birth defects or, indeed, any other unwanted complication of pregnancy? The most obvious possible factor is radiation, ionizing or not. This matter has been examined in detail elsewhere in this paper with the conclusion that all kinds of radiation, whether alone or in combination, exist only at levels well below those known to have any biologic effect in man. Other potential factors include ergonomic conditions and occupational stress. Mackay points out that those ergonomic factors that can be related to fetal distress or reduced fetal growth are associated with hard physical activity at work and not with the sedentary kind of activity found in VDT workers. Occupational stress is perhaps more nebulous: its study must take into account the kind of work being done, the organization of work, demands on work productivity, and interpersonal relationships in the workplace. To these must be added stresses that may occur outside the workplace and emotions that may be brought about by the pregnancy itself. It would not be easy, therefore, to isolate a single stressor (e.g., the VDT) as a cause, and in any event the environment of the office rather than the apparatus itself is more likely to be a contributing factor.

Cataracts

Although an association between cataracts and VDT use has been reported only by one investigator, the subject has received considerable publicity. A panel of experts who evaluated the matter pointed out that the report had not been published in a refereed scientific journal. Furthermore, of the ten cases reported, six had inconsequential opacities not appreciably reducing visual acuity and the remaining four cases had either a known preexisting disease or exposure to a cataractogenic agent. The causes of lenticular opacities are many, and the vast majority of visually disabling cataracts are associated with aging. A panel of experts has also considered the kind of study that would be required to establish whether there is a causal relationship between VDT use and cataracts and concluded that, at the time of writing, the size, complexity, and cost of such a study would make its pursuit both unjustifiable and unreasonable. Bergqvist surveyed a number of studies and came to the conclusion that neither epidemiologic nor experimental data support the suggestion that VDT exposure could lead to cataract formation. The matter was also considered briefly by another group, which came to the conclusion that it was improbable that VDTs would produce cataracts in exposed workers. This conclusion is supported by the scientific data indicating that none of the radiations alone, or all of them cumulatively, at levels associated with VDTs, is capable of inducing cataracts.

Skin Rashess

Linden and Rolfsen discuss ten cases of facial rashes, described as dermatitis, among VDT operators. The condition subsided rapidly when the employees were away from VDT work. In one case they were able to reproduce the condition by using an electrostatic generator. Raising the relative humidity of the workplace and antistatic treatment of carpeting apparently cured the condition. Similar conditions have been reported by others.

Although the VDT may contribute to a greater or lesser extent to the static electricity load, one cannot entirely separate it from other factors tending to degrade indoor climate. To reduce the buildup of static charges, the relative humidity of office air should be raised wherever practicable (problems are caused in this respect by very low outdoor temperatures) and measures should also be taken to reduce the chance of generating static electricity on carpeting and other materials.

Repetition Strain Injuries

Reports from some countries, notably Australia, indicate that there is an increased incidence of conditions of this sort in users of electronic keyboards and, in particular, VDTs. Browne et al have made a comprehensive survey of repetition strain injuries and cite keyboard operation in occupations concerned with information and data processing as appearing to carry an increased risk of injury. In some users the condition has become so severe as to require clinical management (including surgical intervention). Classification difficulties and especially the loose and often incorrect use of the term "tenosynovitis" have made interpretation of

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reports difficult. Further work is required to delineate the precise musculoskeletal conditions in relation both to keyboard design and, more generally, to work station layout so that preventive measures may be taken by equipment designers and manufacturers.

Photosensitive Epilepsy

Cakir et al. discuss this subject in some detail. Between 1% and 3% of the epileptic population (5 to 15 per 100,000 of the total population) is subject to seizures provoked by visual stimuli, but the incidence falls off quite rapidly after the age of 16 to 18 years. The optimum flash frequencies to induce convulsions are between 10 and 35 Hz, although one study showed that convulsions could be produced at frequencies between 10 and 48 Hz by patterned stimulation. More recently, a leading article in the Lancet pointed out that striped patterns with a frequency of about three per degree-of-arc can be epileptogenic. However, it is unlikely that anyone will experience photosensitive epilepsy for the first time while operating a VDT. Modern displays do not flicker at the most troublesome (epileptogenic) frequencies and the lines of text on a VDT screen are, at the usual working distances, considerably coarser than the three per degree-of-arc stripes most likely to provoke seizures. Binnie et al. have recorded EEGs from photosensitive subjects while viewing VDTs and have consistently failed to elicit epileptiform activity, whereas with black and white television sets, using an essentially similar procedure. Binnie et al. have evoked epileptic discharges in 40% of photosensitive subjects. There are thus no known reports of VDT-caused convulsions. It seems reasonable, however, to recommend that any known epileptic who is sensitive to photic stimuli should consult a physician before undertaking work with VDTs.

Polychlorinated Biphenyls (PCBs)

In a few cases, emissions of PCBs have been attributed to VDTs. However, although such emissions may occur, they are not directly due to the VDT but result from PCB deposition on the VDT because of air contamination from other sources. PCB levels in a room in which VDTs were used were measured by Digerens and Astrup and found to be 56 to 81 ng/m³ as against 0.1 to 1 ng/m³ in the outdoor air. Although PCB levels in the air in other parts of the same building were not measured, it was inferred that the electrical components within the VDTs were the probable source of contamination. A different conclusion was reached by Benoit et al. who had already experienced PCB contamination of the air in their own laboratory from caulking materials located near the fresh-air intake. PCB emissions were found from eight VDTs used in a building where the ambient air was contaminated with PCBs, but PCB emissions were also found from an electric typewriter used in the same building. On the other hand, no PCB emissions were found from VDTs of the same type used in another building in which the air was not contaminated with PCBs. It was concluded that PCBs were deposited onto the VDTs from the contaminated air and did not arise from the electrical components in the terminals.

Medical Surveillance

A panel of experts concluded: "We find no scientifically valid evidence that the use of VDTs per se causes harm, in the sense of anatomical or physiologic damage, to the visual system." A mandatory program of ophthalmologic examinations cannot, therefore, be justified. Working with VDTs is but one of many types of occupation requiring continuous near-visual effort. Individuals who complain of ocular discomfort or difficulty in reading displays should seek medical advice, and such advice may include periodic surveillance. Types of test that apply to VDT operators are discussed by Wolbarsht and Landers. A person seeking medical advice should indicate clearly to the physician that he or she works with VDTs and should be able to state the working distance from the eyes to the display screen.

Conclusions and Recommendations

Various physical aspects of work with VDTs which may affect the user's health have been reviewed. Visual factors, lighting conditions and other environmental parameters, work station design and layout, radiation emissions, other health concerns (pregnancy outcomes, cataracts, repetitive strain injuries, skin rashes, photosensitive epilepsy, polychlorinated biphenyls), and medical surveillance have been discussed. Although psychosocial factors may affect the health of VDT workers and are to a certain degree inseparable from physical factors, they have not been addressed in this paper.

A critical review of the available data leads to a conclusion that the various factors discussed can be divided into three categories. The first category includes factors that may lead to possible health problems. Preventive measures can and should be taken to eliminate them. The second category constitutes unresolved issues which may or may not prove to be significant. In the third category belong the factors that have been of concern and have become issues but which, on the basis of scientific evidence, can only be classified as nonproblems.

Visual and musculoskeletal problems remain the two commonest areas of concern. They are usually a direct result of a lack of sufficient attention to ergonomics in terms of workplace design and layout, and perhaps also to problems with visual accommodation. These two main causes of operator problems, which arise from a number of specific factors as reviewed in the paper, can be eliminated or greatly limited. Some recommendations as how to limit them have been made, but as knowledge in this field is increasing rapidly, new advances should be monitored and new advice implemented.
Issues such as ionizing and nonionizing radiation, ocular pathology (including cataracts), epilepsy and PCBs have been frequently cited in nonscientific publications as problems, but in reality are not. Ionizing radiation is either not emitted from VDTs (monochrome displays) or only in extremely small quantities that are below the ambient background. Various types of nonionizing radiation are emitted, but the exposure levels of VDT operators are so low that on the basis of available scientific data, these radiations separately, or cumulatively, are unlikely to cause an adverse biologic effect. The three remaining issues have not been shown to be directly associated with work on VDTs.

Adverse pregnancy outcomes, repetitive strain injuries, and skin problems have not been fully resolved and require further investigations. The evidence on effects of work with VDTs on pregnancy outcomes is somewhat inconclusive and rather indicative of a lack of relationship. Considering the importance of the issue, there is a need to establish, with as high a level of confidence as possible, whether or not work with VDTs has an adverse influence on the pregnant woman or her offspring. Skin problems have been reported only in a very small number of cases and are likely to be remedied easily through better control of the general environment of the workplace.

The WHO group of experts endorsed the following general recommendations. They are not all-inclusive, and many more specific recommendations are included in the text and elsewhere.1.12

1. VDT workers, similar to other workers whose jobs pose high visual demands, should have their vision corrected by proper spectacles, if needed.

2. The design of VDTs should be such as to ensure high image quality. Essential factors are resolution, display stability, display polarity, luminance, and contrast.

3. Lighting conditions are critical in eliminating visual discomfort. Specific measures must be taken to eliminate reflections and glare. The lighting of the workplace should be properly adapted to the task to be performed.

4. Modern VDT displays have the glass surface specially treated to ensure low reflectivity; no external filters are then needed. Use of glare filters on older VDTs might eliminate reflections but at the same time might degrade the luminance of the display and its resolution, resulting in an increase in visual fatigue. Elimination of sources of reflection is the desired solution.

5. Because of the work demands put on VDT operators, it is important that environmental factors such as temperature, humidity, and noise level be kept within limits that are at least in the acceptable range and are preferably as near optimal as possible.

6. One of the most critical issues is the design and layout of the work station so as to eliminate sources of postural problems of the operator. This requirement is not only very critical but also challenging and difficult, as there are many different types of work and vast anatomic differences between VDT operators. There are already many well-established ergonomic principles that should be followed, but further research in this field is still required.

7. There is no need for periodic checks of x-ray radiation, as there is no inherent factor that may cause x-ray emissions to increase as a VDT ages.

8. There is no valid reason for VDT operators to wear a lead apron or any other metal apron, whether they are pregnant or not.

9. When exposure of the VDT operator is compared with available scientific data on health effects of radiofrequency fields and with recommended exposure limits, it is very unlikely that these fields have any health significance. Nevertheless, it is good practice to avoid unnecessary exposure to nonionizing radiation from the adjacent VDTs, unless the emissions from the equipment have been measured and are found to be low.

10. No scientifically established physical factors justify the transfer of a pregnant VDT operator to a job in which VDTs are not used. Transfer for other reasons may, however, be found justifiable.

11. Eye examinations should be given to VDT operators who experience visual problems while working with VDTs.

12. Where VDT operators experience skin rashes, indoor climate factors (e.g., humidity) and static electricity should be measured and proper controls implemented where required.

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Appendix 1

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