

Video display terminals and health

A technical and medical appraisal of the state of the art

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ABBREVIATIONS

The following abbreviations are used throughout the text and tables without explanation:

ACGIH	= American Conference of Governmental Industrial Hygienists
ANSI	= American National Standards Institute
BRH	= US Bureau of Radiological Health
CRT	= cathode ray tube
$d\mathbf{B}/dt$	= time derivative of the magnetic field
ELF	= extremely low frequency
HF	= high frequency
IBM	= International Business Machines
IR	= Infrared
IRPA	= International Radiation Protection Association
LF	= low frequency
MF	= medium frequency
NaI(Tl)	= sodium iodine crystal, Tl-doped
NIOSH	= US National Institute for Occupational Safety and Health
NRC Panel	= US National Research Council's Panel on Impact of Video Viewing on Vision of Workers
SPL	= sound pressure level
SSI	= Statens Strålskyddsinstitut (Swedish National Institute of Radiation Protection)
TLV	= threshold limit value
UHF	= ultra high frequency
UK	= United Kingdom
US	= United States
UV	= ultraviolet
VDT	= video display terminal
VHF	= very high frequency
VLf	= very low frequency
WEAC	= US Food and Drug Administration, Winchester Engineering and Analytical Center
WHO	= World Health Organization

VDTs are more frequently being used in most countries. In newspaper offices in the US and Canada, for example, the number of VDTs increased from 155 in 1971 to 30 000 in 1981, a figure which corresponds to a 70 % annual increment! The annual growth of VDT users in Canada is supposedly 20—35 % per year at present. By the year 2000 forecasts suggest that 60 % of the North American workforce will be using VDTs (127).

Along with this expanding use of VDTs, reports and expressed concern about adverse health effects among VDT operators have appeared. A number of health effects have been discussed, such as eye problems (both discomfort and cataract formation), headache and stress, skin rashes, muscle pain, and miscarriages or birth defects.

Some of these discussed effects (eg, miscarriages, birth defects, or cataract formation) have not been shown to have any relationship with VDT work. Other effects are related but are also found frequently in non-VDT workers, and in circumstances where the work requirement or work environment, rather than the VDT unit per se, appears to be the (major) decisive factor (stress, muscle pain, and possibly headache and skin rashes). Some eye discomfort problems do appear to be linked specifically to work with VDT units.

Objective of the report

The report summarizes and attempts to evaluate the considerable volume of research results and discussion which has appeared on the subject of the possible health implications of work with VDTs. It is limited to the use of VDTs in the presentation of written text, and also to VDTs based on CRT techniques.

The adverse health effects which have been discussed in relation to VDT work include eye problems, musculoskeletal discomfort, skin rashes, adverse pregnancy outcomes, headaches, psychosocial problems, etc. There is no disputing the reality of the observed effects, be they skin rashes, neck aches, or abortions. What must be elucidated is the possibility of any causal relationship between these health effects and VDT work.

The effects discussed should in principle be assigned to one of the following groups:

1. An adverse health effect directly related to a unique character of VDT work. Other complementary

factors may be involved, but the fact that the work is performed on a VDT contributes a unique factor determining the health effect.

2. An adverse health effect due to the presence of one or several factors, of which VDT work may provide one (or several) of the factors. However, the factor(s) provided by the VDT situation does not have to be unique; the same factor may appear in other (similar) situations (eg, in other types of office work, in which similar tasks are performed on paper).

3. An adverse health effect due to factors (known or unknown — possibly of stochastic character) not related to the VDT work situation.

When causative factors are discussed, both physicochemical and psychosocial aspects are probably relevant. Psychosocial factors have been discussed as possible causes of the noted health complaints. They also add contributing or confounding factors which must be considered when the physicochemical background of some health effects are evaluated.

This report discusses, by and large, the physicochemical factors. This limitation does not imply that psychosocial factors are unimportant — on the contrary, indications are that they may have a major influence on the noted health effects. However, knowledge of these factors is limited in comparison to available information on the physicochemical effects — and the possibility of reaching a viable consensus on their influences is comparably small.

In some respects, however, psychosocial factors will be discussed in detail. Job categories have a considerable influence on many noted health complaints and are discussed when appropriate. Many studies depend on descriptions (and evaluations) of effects by the VDT operator (or the investigator). In addition the attitude towards VDT work may well lead to, eg, recall bias (of the operator). This phenomenon may complicate the evaluation of epidemiologic investigations and may assign a health effect to group 1, when an assignment to group 2 or 3 would be more appropriate. In addition the psychological impact of, eg, the public discussion on pregnancy and VDT work should be considered.

Structure of the report

The “mode of attention” of reports and evaluations on VDT and health problems varies considerably.

Two extreme modes have been characterized (127): *machine centered*, emphasizing the technical and physical aspect of the VDT units and evaluating suggested or indicated health problems in terms of possible VDT-originating factors, and *people centered*, emphasizing the environmental and psychosocial context in which the VDT technology is introduced. I consider both modes obvious assets when discussing VDTs and health aspects and have tried to structure the information in this report accordingly. The report has thus been divided into the following two sections, reminiscent (although not strictly) of these two modes of attention: (i) a technical occupational hygiene description of factors (VDT or non-VDT originating) which may conceivably be of interest with respect to VDT health effects and (ii) a medical-ly and phenomenologically oriented description of reported/suggested/alleged health effects, when possible, discussed with reference to the technical part.

An additional reason for the "two-mode" presentation is the multifaceted relations involved. Information in section I (eg, on low X-ray levels) can be related to several chapters in section II, and, conversely, information in section II (eg, on no observed adverse pregnancy outcome) can be related to several chapters in section I.

Section I

The technical occupational hygiene section comprises eleven chapters. The extent of discussion in each chapter is primarily related to the extent of available literature. Two topics, however, have been discussed in more detail, electromagnetic radiation and fields (chapters 2—5) and display characteristics and work-room lighting (chapter 8). These discussions are motivated by the importance of the topics with respect to cataracts, adverse pregnancy outcomes, and asthenopia.

First is a brief discussion of VDTs based on the use of CRTs. Non-CRT-based VDTs are briefly commented on but are not further considered in this report. Thus the term VDT will (unless otherwise indicated) be synonymous with CRT-based VDTs.

Next, in chapters 2—6, there is a description of electrostatic and electromagnetic phenomena in conjunction with VDTs. This description is specified — according to the frequency of the radiation or field — into ionizing, optical, and Hertzian radiation or fields and electrostatic fields, and it is followed by a short presentation (chapter 7) of the few (existing) data on audible and ultrasonic noise. Presently available information and the consensus suggest that the two groups of factors presented in chapters 2—7 are only of minor importance for health effects on VDT workers. (It is possible that new data may force a modification of these evaluations in some areas. Nevertheless, present data support the given evaluation.)

Following are four other groups of VDT work-related factors with possible impact on health and comfort in VDT-related jobs: display of information on the screen (oscillations, structure and luminance) (chapter 8), the operator and workstation design (chapter 9), the office environment (physical and chemical factors) (chapter 10), and job design and psychosocial factors (chapter 11).

Section II

The medical-epidemiologic part of the report consists of nine chapters (chapters 12—20). Considerable attention has been focused on eye problems since they are the main present contenders as specific VDT-related effects. A thorough discussion is also included of the possibility of miscarriages or birth defects, since considerable apprehension and widespread concern about this possibility are found among many VDT operators.

Chapter 12 gives some general comments on performed field surveys and epidemiologic investigations, while chapters 13—15 present a discussion of the possible effects of VDT work on the eyes (discomfort as described both by subjective statements and by medical examination, and the possibility of pathological changes). In chapters 16 and 17 the topic is headache and stress. Skin rashes (chapter 18) and musculoskeletal complaints (chapter 19) are next, followed by a discussion of the possibility of adverse pregnancy outcome due to VDT work (chapter 20).

Terminology and definitions

Definitions of certain phenomena found in the VDT-related literature are unfortunately often ambiguous or vague.

One example is polarity and contrast. In this report, a screen with positive polarity is defined as a screen with dark characters and bright background, negative polarity implying bright characters and dark background. (Reverse definitions are found in some of the literature.) All quotations have been adjusted accordingly.

The terms used to describe the subjective discomfort of the eyes vary considerably between different reports and make comparison rather difficult. In this report, the term asthenopia has been defined as "any subjective visual symptom or distress resulting from the use of one's eyes." This definition has been suggested by the NRC Panel (94).

Various field surveys have been conducted in which variations in, eg, job types are correlated with occurrences of health effects. Unfortunately, some studies are not sufficiently specific as to the job types or the effects. Differences in specific symptoms within the general syndromes of eye strain, headache, muscle discomfort, or skin trouble are probably of considerable importance when the effects of VDT work are being evaluated.

Technical and occupational hygiene aspects of video display terminals

1. General description of a video display terminal

Overall construction principles of the cathode ray tube

The following description is based on the book by Grivet et al (44) and the book entitled *Reference Data for Radio Engineers* (57).

A CRT is constructed according to the same general principles regardless of its application, in a television set, a VDT, etc. A description of the major components follow (figure 1).

A *cathode* serves as the electron source.

A *grid* is used to modulate the intensity of the electron beam. The electron beam can be cut off by a sufficient increase in the potential difference between the grid and the cathode (the former being negative to the latter). Grid potentials are typically -10 to -100 V.

A series of two to three *anodes* accelerates and focuses the electron beam. Focusing (and also some modulation) of the beam is achieved by variation in the individual anode potentials (typically at a few hundred to a few thousand volts positive).

Deflecting devices regulate the impact area on the screen. This action is normally accomplished by an arrangement of magnetic coils outside of the tube.

The trajectory of the beam depends on the magnetic fields induced by the coils, in a complex relation; aberrations, distortions of the beam shape, etc, do arise. (Electric deflection devices occur infrequently in VDT applications.)

The CRT *screen* consists of two layers. The first is a metal layer with a high potential [postacceleration potential of up to about $+25$ kV (VDTs)]. This potential accelerates the electrons in the latter part of the trajectory. The layer also reflects light from the phosphor towards the observer and thus increases the brightness of the screen image. Another layer consists of fluorescent screen material, "phosphor," where the electron energy is converted to light. This phosphor is in principle constructed of a mineral (base) with a small amount of an activating (metal) material. Some examples are shown in table 1.

The *glass envelope* of the CRT is conductive and has a permalloy layer, to shield the tube from electrostatic and magnetic fields.

The tube is sealed off to maintain a *vacuum* of some 10^{-6} mm Hg (about 10^{-4} Pa). Precautions are also taken against residual gas and ions produced within the tube.

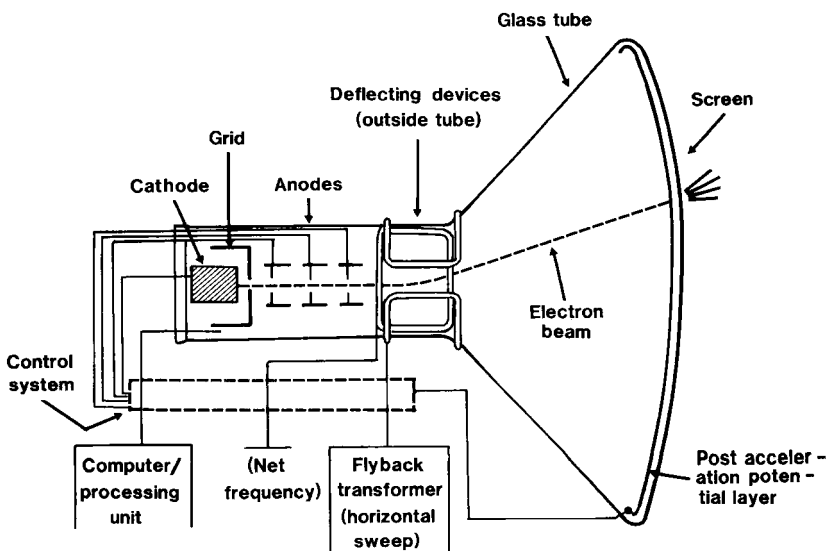


Figure 1. Principle of the CRT/VDT design.

Table 1. Characteristics of some screen materials used in CRTs (44; 57; Hansson C, Versal AB, personal communication).

Name	Base (mineral)	Activating metal	Intensity maximum (nm)	Persistence of emission ^a
P ₄	Zinc sulfide and cadmium sulfide	Silver	440 and 525 (white)	100 μ s
P _{22G}	Zinc silicate	Manganese	525 (green)	Medium ^b
P ₃₁	Zinc sulfide	Copper	522 (green)	70 μ s

^a Decay time (from 100 to 10 % emission). Literature values differ considerably; see also page 28.

^b Medium = 1–100 ms (57). Values from the literature differ considerably, from 60 μ s to > 20 ms.

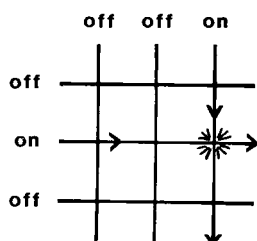


Figure 2. “Matrix” system used in several types of non-CRT-based VDTs. Some of the lines in the matrix carry current, determined by the information to be displayed.

order to avoid distortions, unwanted lines as the beam returns, etc. Further discussions of these phenomena are found on pages 21–22 (frequencies) and 24 (magnetic fields).

The phosphor used in VDTs must be determined according to color, persistence, etc. Phosphors vary in persistence time from P₄₆ (Flying Spot Scanner) with 160 ns to, eg, P₁₅₈ (Medium Persistence Yellow) with 140 ms. Phosphors used for display purposes normally have persistence times of around 100 μ s or longer. (These literature values vary considerably between different investigations, see also page 28.)

Application of the cathode ray tube to video display terminal operation

The generation of text or a picture on the screen is dependent on the following three cyclic procedures.

1. A saw-tooth magnetic field with a periodicity (refresh rate) of between approximately 50 and 80 Hz applied to the vertical deflector system: This field gradually lowers the electron beam “down” the screen and then quickly returns the beam to the upper limit of the screen. This frequency governs the “refresh rate” of the screen information.

2. A second saw-tooth magnetic field (“flyback”) which gradually moves the beam towards the right of the screen and then quickly returns the beam to the far left: This field, with a frequency of between (normally) 15 and 25 kHz is generated by the current from the flyback transformer and is applied to the horizontal deflecting system.

3. Modulation (on/off) of the electron beam intensity in order to produce light or dark spots along the horizontal sweep: The maximum rate of on/off signals corresponds to the frequency of “pixel” (picture element) generation, and is usually performed with a digital clock frequency on the order of 5–10 MHz. This external signal from the computer or the processing unit (keyboard, etc) is applied to the gate. The potential on the gate can then cut off the electron beam, and a dark spot is produced.

The two “fixed” (procedures 1 and 2) and one “varied” (procedure 3) signal must be correlated in

Video display terminals of noncathode ray tube design

VDTs can be based on techniques other than “conventional” CRTs (as have already been described). Some examples follow briefly.

Plasma displays utilize a thin gas layer (neon and argon), which can be ionized by a current. This current is delivered by conductors, and ionization — and thus visible discharge — occurs only at the junction of two “live” conductors (figure 2) (68).

Liquid crystal display techniques are also being developed. In these displays light is refracted in liquid crystals, the refractive capability of which is determined by electric fields. The pattern and sequency of the currents in the “matrix” (figure 2) determines the light and dark areas of the screen (2).

Additional designs, eg, combining CRT techniques with plasma (134) or a current multiplier (74), are also being developed.

These new VDT techniques have both advantages and disadvantages over “conventional” CRTs. Some problems are inherent in the design, while others are probably amendable by further development. These problems concern visual characteristics such as resolution, contrast, luminance variation, etc. For instance all the examples thus far given for VDTs include a “matrix” based on the actual physical construction of individual cells (pixels — eg, intersections in the maze in figure 2 or individual cathodes in the CRT or plasma technique). Thus, improving resolution by the construction of more cells may be more costly with these techniques than with conventional CRTs.

This report has been restricted to conventional CRT-based VDTs. An evaluation and discussion of

the visual functions of some non-CRT VDTs can be found in the report of the NRC Panel (94).

2. Electromagnetic radiation and fields

VDTs based on the CRT are a source of several distinct types of electromagnetic radiation. Such emissions are characterized by a number of interdependent parameters, eg, frequency, wavelength, electric field intensity, magnetic field intensity, energy/quanta, effect density (W/m^2), etc. (See appendix 1.)

The range of the electromagnetic spectrum in terms of frequency is given in table 2.

The electromagnetic field has both an **E** and a **B** (or **H**) component, the relations between which are rather complex. (See appendix 1.) For practical reasons, the field is separated into a near field (less than ~ 1 wavelength from the source) and a far field. At the operator's distance from the VDT, the near field is only of interest with respect to radio frequencies and VLF/ELF.

Most measurements of radiation and fields are averaged over time (during the whole pertinent cycle) and over space (for at least a substantial part of the screen). This procedure is possibly inappropriate in some specific situations, two of which have been given some attention, ie, nonsinusoidal magnetic fields, where the change in time of the magnetic field may be of interest (see page 24) and visible light, where the individual pixels radiate most energy during a limited time of each cycle (see pages 28—30).

Potential electromagnetic radiation and fields from video display terminals

A VDT based on the CRT is a potential source of several distinct electromagnetic spectral bands. The actual intensity of each band, frequencies, etc, depend on the detailed technical design of the terminal, shielding, etc.

X-ray radiation arises within the CRT tube when the fast electrons are quickly slowed down by the screen material. X-ray radiation (ionizing radiation) from VDTs is discussed in detail on pages 17—18.

Optical radiation is purposely derived by the phosphor material in the screen, when it interacts with electrons. The overall (time average) emission levels are discussed later (pages 19—20), while details of visible light emissions are discussed under display characteristics (see pages 27—30).

High radio frequency radiation does appear, apparently in relation to the frequency of pixel formation, ie, the intensity modulations of the incident electron beam towards the screen (regulating the intensity of the "dots" on the screen). This frequency is then related to the frequency of the information signal system. (See pages 20—25.)

Table 2. Frequency of different electromagnetic radiations and fields.^a

Name	Frequency range (Hz)	Wavelength (m)	Energy of photon
<i>Ionizing radiation</i>			
X-ray radiation	$> 3 \cdot 10^{17}$	$< 10^{-9}$	$> 1.2 \text{ keV}$
Ionizing UV radiation	$3 \cdot 10^{15} - 3 \cdot 10^{17}$	$10^{-7} - 10^{-9}$	$12 \text{ eV} - 1.2 \text{ keV}$
<i>Optical radiation</i>			
Nonionizing UV radiation	$8 \cdot 10^{14} - 2 \cdot 10^{15}$	$3.8 \cdot 10^{-7} - 10^{-7}$	$3 - 12 \text{ eV}$
Visible light	$4 \cdot 10^{14} - 8 \cdot 10^{14}$	$7.5 \cdot 10^{-7} - 3.8 \cdot 10^{-7}$	$1.6 - 3 \text{ eV}$
IR radiation	$3 \cdot 10^{11} - 4 \cdot 10^{14}$	$10^{-3} - 7.5 \cdot 10^{-7}$	$0.0012 - 1.6 \text{ eV}$
<i>"Hertzian" radiation/fields</i>			
Microwave, UHF radiation	$3 \cdot 10^8 - 3 \cdot 10^{11}$	$1 - 10^{-3}$	.
Radio frequency (high) (VHF, HF) radiation/fields	$3 \cdot 10^6 - 3 \cdot 10^8$	$10^2 - 1$	.
Radio frequency (low) (MF, LF) radiation/fields	$3 \cdot 10^3 - 3 \cdot 10^6$	$10^5 - 10^2$	.
Very low frequencies (VLF, ELF) fields	$< 3 \cdot 10^3$	$> 10^5$	.
<i>Electrostatic fields</i>			
Electrostatic fields	0	.	.

^a Note that the given limits are somewhat arbitrary; different authors use slightly different definitions of some radiation and field categories.

Table 3. Results of measurements on VDT electromagnetic emissions and comparison with some pertinent standards.

Spectral component ^a	Upper limit of emission from VDT ^b	Swedish standards	US standards (BRH or ACGIH)	Number of VDTs examined ^c
X-ray radiation	Not detected (probably <0.1 mSv/year)	5 mSv/year	Approximately 10 mSv/year	Many
Actinic UV	10 μ W/m ² = 0.3 J/m ² , 8 h	30 J/m ² , 24 h	See the ACGIH TLVs (1)	Many
Near UV	<0.1 W/m ²	10 W/m ²	10 W/m ²	Many
Visible light and near IR	<1 W/m ² , sr <150 cd/m ² ^d	..	10 W/m ² , sr 10 000 cd/m ² ^e	Many
VHF, HF (~ MHz)				
E	<0.5 V/m	60—140 V/m ^f	60—614 V/m	Many
H	<0.0002 A/m	0.16—0.4 A/m ^f	0.16—1.6 A/m	Few
MF, LF (~ kHz)				
E	<150 V/m	..	614 V/m ^h	Many
H	<0.1 A/m ^g	..	1.6 A/m ^h	Many
VLF, ELF (~ Hz)				
E	<100 V/m	..	.. ⁱ	Few
H	<1 A/m	..	.. ⁱ	Few
Electrostatic fields				
E	<30 kV/m	..	..	Many

^a See table 2 for definition. The frequency designations in the radio frequencies are approximations only.

^b As detected by the investigations examined. The levels may be somewhat exceeded in exceptional cases. The levels normally refer to those found at 30 cm (or closer) from the VDTs. (See tables 4—12.)

^c Many = more than 50 VDTs examined, few = less than 10 VDTs examined.

^d See comments on top luminance, page 29.

^e Level of "no interest" [See the ACGIH TLVs (1).]

^f Proposed.

^g See the comments on time variations of magnetic fields, page 24.

^h Applicable to frequencies above 10 kHz.

ⁱ The ACGIH is studying this range but has so far (1983) not found sufficient data for establishing a TLV.

Low radio frequency radiation emanates from the horizontal deflection system (flyback transformer, connecting wires, and the screen). (See pages 20—25.)

Very low frequencies arise around the refresh rate (vertical sweep frequency) and apparently depend on both the vertical deflection system (producing a purposeful magnetic field) and modulations of the electrostatic field (positive electrostatic charge modulated by the intermittent negative electron beam). (See pages 20—25.)

Electrostatic fields frequently appear in relation to the acceleration potential of the CRT. (See pages 25—26.)

Radiation or fields with a time dependence that cannot be described by a simple sinusoidal function (of a certain frequency) gives rise to "harmonics" of higher frequencies and lower amplitudes. Thus the bands of the high and low radio frequencies and the very low frequencies each include a fundamental frequency and several harmonics of higher frequencies, most of the energy normally being confined to frequencies within 10 times the fundamental frequency.

Most regions are heavily dependent on the mode of operation of the VDT. This dependency has been explicitly shown for the bands in the high radio frequencies and the very low frequencies (and is self-evident for the band of optical radiation). By special measures (blinking cursor, interlace, etc), subhar-

monics can appear — as shown for the electric component of the band in the very low frequencies.

See also pages 13—15 for a brief description of VDT/CRT technical design.

Measurements of the electromagnetic spectrum

With some exceptions, the whole frequency band from 0 to 10¹⁹ Hz has been investigated with respect to VDTs. Some regions have been examined however only cursorily (or not at all), ie, (i) ionizing radiation between 6 keV (0.2 nm) and 6 eV (200 nm) ("vacuum" UV) [These photons do not penetrate air.], (ii) the lower part of the IR region, and (iii) the high frequency part of the microwave region.

These bands do not include any frequencies where specific types of electromagnetic radiation are expected from VDTs (for fundamental or technical reasons). This rationalization is supported by the (few) investigations performed in (some) of these bands and by the (low — nondetectable) findings in adjacent, more intensively investigated bands.¹

¹ Some isolated readings in the microwave region were found in one investigation from a few terminals only (approximately 1.4 GHz) (125). These findings were interpreted as being "associated with the computer and not the display terminals in the same room [p 303]." The levels were orders of magnitude below current (US, Canadian or Swedish) standards.

The low coverage of the VLF/ELF band is noteworthy, however, and is at least partly due to the absence of reliable instruments [see, eg, comments made by Paulsson et al (95)].

Based on this rationale, the following discussion has been limited to the six described spectral bands, ie, X-ray radiation, optical radiation, high radio frequency radiation, low radio frequency radiation, VLF radiation, and electrostatic fields.

The results of performed measurements are described in subsequent chapters and are summarized in table 3.

The electromagnetic spectrum of radiation from VDTs has been reasonably well investigated. Levels of radiation have been found to be low in comparison to present standards. Thus the present state of knowledge enables the following statement to be made: *VDTs are not a source of harmful intensities of electromagnetic radiation.* This statement is based

on presently known data and is conditional on the failure of the following events to appear:

1. The existence of further (presently unknown) physical processes emitting high-intensity radiation in one of the narrow uninvestigated bands within the VDT.
2. The appearance of new data on biological effects of radiation, correlating harmful effects with intensities of orders of magnitude below presently known levels of harmful effects. (It should be pointed out that, if such would be the case, then the operation of many other industrial or household appliances would be considered equally harmful.)
3. The establishment of a frequency window in a relevant region (for VDT emissions) in connection with appropriate amplitudes.

3. Ionizing radiation

Considerable attention has been given reported cases of miscarriages, skin rashes, and cataracts among VDT operators. Since VDTs are potential sources of X rays, possible causes of these effects, a discussion of measurements performed on X-ray emissions from VDTs is appropriate.

Terms in use are either X-ray or ionizing radiation. The former comprises electromagnetic radiation of frequencies above some $3 \cdot 10^{17}$ Hz, emitted when high-energy electrons are (quickly) slowed down ("Bremsstrahlung"). Ionizing radiation has energies sufficient to cause ionization and comprises a somewhat larger frequency interval, from about $3 \cdot 10^{15}$ Hz (some 12 eV) and above. However, radiation with photon energies below some 5 keV (vacuum UV) is of no practical interest, since these photons do not penetrate air. (See also table 2.)

The background of X-ray radiation varies considerably, values between 0.1 and several millisieverts per year have been found in the literature. In the US and Canada, the background is typically some 1—2.5 mSv/year (133), while West German levels have been quoted as about 1.1 mSv/year (71).

Video display terminals as sources of X-rays

The potential source of X-rays within a VDT is the CRT and, specifically, the inside of the fluorescent viewing screen. The energy of the photons is limited by the high voltage used to accelerate electrons, to

some 10—25 keV (soft X rays), corresponding to a frequency band of $2\text{--}6 \cdot 10^{18}$ Hz.

Normally, due to their limited energies, these X-ray emissions are effectively shielded by the glass screen (133). The fraction that may escape is further attenuated as irradiance decreases fairly quickly with distance (r), although slower than r^{-2} due to the nonpoint source and screen absorption (causing the angular distribution of emitted radiance to be strongly peaked towards the operator). A conservative estimate (133) suggests that the intensity at 40 cm would be "less than half" of that at 5 cm. My own calculations suggest an intensity attenuation from 5 to 40 cm of some 90 %.

Furthermore, the low energies of the photons result in further attenuation in the human body, and tissues deeper than a few centimeters are effectively shielded (133).

X-ray measurements

Some 3 000 measurements have been performed on the possible X-ray emission from VDTs (14, 125, 128, 133). Several models and units were tested in more than one investigation. Most units were tested at 5 cm or less from the screen under normal operating conditions (often with maximum brightness and a full screen). One hundred and twenty-five tests performed by the BRH (14) used also "phase III" test conditions (these test specifications include maxi-

Table 4. Measurements performed on X-ray emissions from VDTs (14, 80, 95, 115, 125, 128, 133).

Dose rate	Number of units ^a (each posting)	Percentage (of all) (each posting)	Accumulated percentage ^b
Emission above background not detected	> 1 388	47.0	47.0 (68.5)
< 1.0 $\mu\text{Gy/h}$	> 626 ^c	21.2	68.3 (99.5)
< 2.0 $\mu\text{Gy/h}$	925 ^d	31.4	99.6 (not included)
< 4.4 $\mu\text{Gy/h}$	3 ^e	0.1	99.7 (99.6)
4.4–17.6 $\mu\text{Gy/h}$	8 ^f	0.3	100 (100)

^a Total number of units = 2 950.

^b Accumulated percentage. Percentage with the Bell Canada results deleted (see footnote d) in parentheses.

^c Implied: no X-ray emission detected above the background.

^d Bell Canada tested 925 units and detected levels of 0.0–2.0 $\mu\text{Gy/h}$. However the test results as presented contained some anomalies. Furthermore, the Canadian Radiation Protection Board retested several of the tested units and failed to find any emission. The Board apparently found these Bell Canada data questionable (133).

^e One unit < 2.8 $\mu\text{Gy/h}$ (133); two units had emissions detected at 3.5 and 3.7 $\mu\text{Gy/h}$, respectively ("phase III testing") (14).

^f All these units were tested by "phase III" conditions (14).

mum voltage and a worst-case component or circuit fault still compatible with a legible screen) in order to find the (theoretical) X-ray emission maximum. Some investigators (95, 128, 133) used more elaborate detection techniques in attempting to find a measurable emission (see the following discussion).

A summary of these measurements, performed in Austria, Canada, Italy, Sweden, the UK, and the US, is presented in table 4. [A more detailed summary of most of these measurements can be found in the report of Zuk et al (133).]

Efforts have been made to detect the actual X-ray emission from VDTs by various methods. In a detection chamber (shielded from background), 52 units were examined without any emission being found. The limit of detection was reported to be 10^{-11} Gy/h (133). With the use of a germanium detector (limit of detection < 10 nGy/h) in a shielded room, four

VDTs were examined without any ionizing radiation being detected that could be attributed to the VDTs (95). With a NaI(Tl) scintillation detector and a pulse height analyzer, an emission of some 25 nGy/h was detected from a VDT. Emission bands appeared at 5, 15, and 30 keV. The operating conditions were normal, with a full screen. The same VDT gave off an additional 25 nGy/h at 20 keV under fault conditions (128).

Compliance with standards

In many countries technical emission standards for CRTs (applicable to VDTs) are set at 4.4 $\mu\text{Gy/h}$. It is apparent that practically all VDTs tested (> 99 %) comply with these emission standards. Those failing to do so (only found during the phase III test conditions mentioned on page 18) in the US were removed from or denied access to the market (14).

The International Commission on Radiological Protection has recommended a dose equivalent limit of 0.5 Sv (non eye exposure) and 0.15 Sv (eye exposure) as being "below the threshold levels for non-stochastic effects [p 46]" (60). (Nonstochastic effects include those involving the eyes, skin, and fetuses.)

National standards for the population at large (not radiation workers) in, eg, Sweden is 5 mSv/year. Extensive testing of VDTs under operating conditions have failed to detect any VDT with X-ray emissions giving dose equivalents in excess of these standards.² In general no ionizing radiation was detected unless elaborate procedures were used to eliminate the background influence. [In one study (95) a decrease in the background levels was actually noted at the operator's position, due to the shielding of the background by the VDT.]

² Theoretically, these standards could be exceeded for operators sitting very close to one of the eight noncompliance VDT models. However, any reasonable assumptions as to viewing distances, attenuation, shielding, normal technical work conditions of the VDT, etc, result in a dose equivalent from VDTs far below these standards.

4. Optical radiation

The range of wavelengths (100 nm to 1 mm) covered by optical radiation comprises nonionizing UV, visible light, and IR.

The UV region of 200–315 nm is termed "actinic" UV (comprises UV-B/-midUV/erythral UV and UV-C/far UV/germicidal UV. UV-C also in-

cludes some vacuum UV, which does not penetrate air). Actinic UV is associated with (most) biological effects ascribed to UV radiation (59).

The spectral emission curves of CRT phosphors (P_1 – P_{51}) are registered with the Joint Electron Device Engineering Council (14). These spectral emis-

sions show a varied distribution throughout the 300 to 800 nm band (visible light and UV and IR bands directly adjacent to the visible region). (See figure 3 for an example of an emission curve). Thirty phosphors have their maximum emission in the 500 to 600 nm band (green color).

At far infrared, only “normal” thermal radiation has been detected (133).

Measurements of optical radiation

Measurements performed on a number of VDTs are reported in table 5 (near and actinic UV) and table 6 (visible light and near IR). The UV measurements show irradiances of less than 0.1 W/m² (most in-

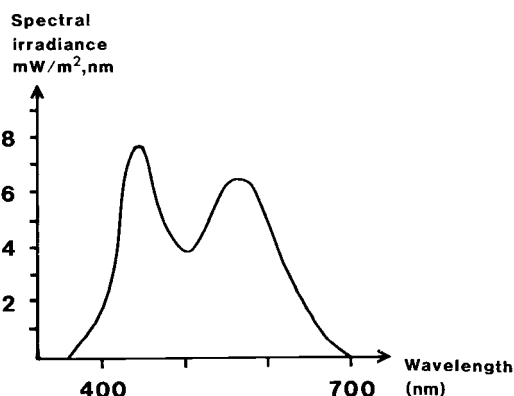


Figure 3. Spectral emission of a P₄ phosphor (44, 95). Spectral irradiance taken from the experimental setup in the report of Paulsson et al (95).

Table 5. Ultraviolet irradiance from VDTs in the near and actinic regions. (ND = not detected)

Number of VDTs tested	Distance (m)	Wavelength range (nm)	Irradiance (W/m ²)	Reference
1	0.01	320—400	$1.8 \cdot 10^{-4}$	Wolbarsht et al (128)
3	Close	230—315	ND (2 VDTs) 10^{-5} (1 VDT)	Paulsson et al (95)
		315—400	0.008—0.024 (3 VDTs)	
35	Contact ^a	320—400	$< 5 \cdot 10^{-4}$ — $3 \cdot 10^{-3}$	Murray et al (83)
136	Contact ^a	320—400	$< 5 \cdot 10^{-4}$ (119 VDTs) $6 \cdot 10^{-4}$ — $6.5 \cdot 10^{-3}$ (17 VDTs)	Murray et al (84)
4	Contact ^b	350—400	$2 \cdot 10^{-4}$ — $3 \cdot 10^{-3}$	Weiss & Petersen (125)
1 ^c	Contact ^b	350—400	$< 10^{-2}$	Weiss (124)
33	0.40—0.50	320—400	$5 \cdot 10^{-2}$ (maximum, 10 VDTs) approximately $1 \cdot 10^{-2}$ (mean, 10 VDTs) ND (23 VDTs)	BRH (14)
1	0.50	200—320 320—400	$1.25 \cdot 10^{-6}$ $< 10^{-6}$	Wolbarscht et al (128)
> 200 ^d	?	240—336	ND	Cox [cited by Zuk et al (133)]
	?	336—440	$< 1.2 \cdot 10^{-1}$? ^e	

^a Filter in contact/close proximity to screen.

^b Filter in contact/close proximity to screen. Detector at distance of 0.5 m

^c One “typical” VDT.

^d Details not reported in the report of Zuk et al (133).

^e In Zuk et al (133), this value was cited as both 0.124 W/m² and 124 nW/m².

Table 6. Visible and near IR emission from VDTs. A direct comparison between radiance (rad) (in W/m²), irradiance (irr) (in W/m², sr), and luminance (lum) (in cd/m²) is not possible.

Number of VDTs tested	Distance (m)	Wavelength range (nm)	Radiance/irradiance/luminance	Reference
1	0.01	200—700	Irr: 0.4 W/m ²	Wolbarscht et al (128)
1 ^a	Contact ^b	400—600	Irr: < 0.1 W/m ²	Weiss (124)
1	0.50	200—700	Irr: $2.2 \cdot 10^{-3}$ W/m ²	Wolbarscht et al (128)
> 200 ^c	?	400—700	Irr: 2.5 W/m ²	Cox [cited by Zuk et al (133)]
	?	700—1 050	Irr: 0.05 W/m ²	
33	?	450—950	Rad: < 10 W/m ² , sr	BRH (14)
1	?	300—700	Rad: $8.9 \cdot 10^{-2}$ W/m ² , sr	Wolbarscht et al (128)
1	?	Visual ^d	Lum: 37 cd/m ²	Wolbarscht et al (128)
136	?	Visual ^d	Lum: 3.4—127 cd/m ²	Murray et al (84)

^a One “typical” VDT.

^b Filter in contact/close proximity to screen. Detector at a distance of 0.5 m.

^c Details not reported by Zuk et al (133).

^d Weighted according to relative luminosity, range 400—700 nm.

vestigations found levels below 0.01 W/m^2). These emissions were generally confined to the region 350–400 nm (near UV). Detected levels of actinic UV (200–320 nm) were about $1 \mu\text{W/m}^2$ (0.5 m) (128) and $10 \mu\text{W/m}^2$ (close) (95). (These levels were below the limit of detection in most investigations.)

The distance normally used was 50 cm, often with the filter in close proximity to the screen.

The irradiance of visible light from the VDTs tested varied between <0.1 and 2.5 W/m^2 and it also showed an (expected) distance variation. The radiance was $0.1 \text{ W/m}^2\text{sr}$ in one investigation, in reasonable concordance with the luminance levels of $3.4\text{--}127 \text{ cd/m}^2$. (Note that the radiance and luminance values are not distance dependent. See also appendix 1.)

Compliance with standards

The Swedish occupational standards for UV radiation (109) are 30 J/m^2 (per 24 h — wavelength region 230–315 nm) and 10 W/m^2 (315–400 nm). The radiation levels indicated in table 5 are at least two to three orders of magnitude below these standards.

There is no Swedish standard for visible light or near IR radiation. Comparison is made with TLV guidelines proposed in 1983 by the ACGIH (1). These

guidelines are supposed to give protection against retinal thermal and retinal photochemical injury. “At luminances less than this value (10^4 cd/m^2), the TLV would not be exceeded [p 91]” (1). The levels of visible light indicated in table 6 are considerably below 10^4 cd/m^2 (by two orders of magnitude or more).

A spectral analysis was made from two VDTs (95), and the retinal thermal injury weighted radiation was found to be 0.12 and $0.29 \text{ W/m}^2, \text{sr}$, respectively, to be compared with the ACGIH TLV of $10^2 \text{ W/m}^2, \text{sr}$ (long-term exposure).

Top luminance

As described in more detail on page 29, the top luminance of the phosphors used have not been measured. Preliminary calculations suggest that they may amount to considerably more than $10,000 \text{ cd/m}^2$, during 5 s/h of VDT viewing (P_{31} phosphor data used for calculations). Thus these luminances (if real) would exceed the “no-interest” guideline of 10^4 cd/m^2 , and a detailed spectral analysis would be necessary. However, according to a preliminary analysis, the ACGIH TLV guideline levels (spectrally weighted) are still considerably higher than the emission levels of these phosphors (Glansholm A, personal communication).

5. Hertzian³ radiation and fields

In this section electromagnetic radiation frequencies below 300 GHz are discussed. This frequency range is used extensively by a large number of ubiquitous technical appliances [radio, television, microwave ovens, radar, etc; see, eg, the criteria of WHO (130)] and also includes fields (inadvertantly) caused by the common net frequency 50 Hz (60 Hz in the US and Canada). The frequency range has been separated into high radio frequencies (VHF, HF), low radio frequencies (MF, LF), and very low frequencies (VLF/ELF) in this chapter (see table 2).

Investigations, discussions, and concern for possible adverse health effects due to these ranges of electromagnetic radiation and fields have hitherto largely been confined to the microwave region (300 MHz — 300 GHz); discussed effects include those on eyes, the nervous system, behavior, reproduction, the cardiovascular system, etc. Observed effects are associated with an accumulation of absorbed energy

from the electromagnetic radiation. Existing occupational health standards are generally designed to limit these thermal effects.

Increased attention is now also being devoted to lower frequencies, including VLF and ELF (0 — approximately 500 Hz, including the net frequencies). [See, eg, the reports of De Matteo (28), Gamberale et al (37), Hansson-Mild et al (51), Löfstrand & Bergström (73), Marha et al (75), Stuchly et al (111), the University of Ottawa (121), and WHO (130).] So far, research results on effects of these lower frequencies are limited. As stated in a BRH report: “Research information on bioeffects for frequency range 15–125 kHz is lacking, so empirical estimates of injury are not possible [p 17]” (14).

Background levels

The backgrounds of microwave radiation and radio frequency fields are due to natural sources (atmospheric electricity, sun, thunderstorms, etc), deli-

³ The name “Hertzian” implies frequencies below 300 GHz.

berate man-made emitters, and unintentional man-made emitters (130). The overall intensity exposure in the range of approximately 10 kHz — 300 GHz for the US urban population has been estimated by Tell & Mantiply in 1978, cited by WHO (130), as:

<0.05 W/m² for 50 % of the urban population
 <0.1 W/m² for 95 % of the urban population
 <1 W/m² for 99 % of the urban population.

The background of the **E** field (100 kHz — 500 MHz) measured by Terrana et al (115) in nonshielded rooms was some 0.2—0.3 V/m.

The magnetic fields from a hand drill, a high fidelity loudspeaker, a television set, and a car engine ranged between 0.01 and 16 A/m (varied distance) in the kilohertz region. The dB/dt (time derivative of the magnetic field) from the same sources varied between 0.05 and 360 mT/s (95).

Electric power station workers may be exposed to 50- or 60-Hz fields of some 10 kV/m (**E** field) and between some 20 and 65 A/m (**H** field) (111).

A number of household and office devices have been tested for their VLF/ELF magnetic field intensities (111). An electric typewriter, a pocket calculator transformer, a baseboard heater, an electric kettle, a hair dryer, and a hand mixer had magnetic fields between 0.2 and 9.3 A/m — with frequencies of 60 Hz (and harmonics) (the distances were not specified). The magnetic fields in various indoor locations (laboratory, office, kitchen, living room — with or without fluorescent light and television) varied between 0.02 and 0.19 A/m.

Measurements of high radio frequency (~ megahertz) fields

In some studies, strong electric and magnetic fields (on the order of 10³ V/m and 1 A/m, respectively) have been measured around VDTs (83, 111). These measurements were examined by the authors and by the BRH and were considered to be caused by a capacitive coupling between the Narda meter (instrument used for measuring **E** and **H**) and the flyback transformer. Some other instruments, when used on the same VDTs, have not confirmed these high readings (111). [See also the reports of the BRH (14) and Zuk et al (133).] The conclusion drawn from these investigations was that of “no detectable emissions” in the high radio frequency (MHz) region from VDTs. The Narda instrument used has a limit of detection of some 50 V/m (**E**) and 0.7 A/m (**H**) (111).

Using more sensitive instruments, however, consistent measurements have been obtained in the megahertz region. These fields appear to be very localized and thus vary considerably with distance, the position of the measuring instrument around the VDT, and the activity of the VDT. Typical readings vary between <1 mV/m at a 1-m distance to 0.5 V/m “at surface” (**E** field) and probably between 0.1 and 200 μ A/m (**H** field, 5- to 30-cm distance). The frequency range used by these emanations is 1 to 200 MHz, with most activity concentrated around approximately 3—30 MHz (see tables 7 & 8).

As indicated by Weiss (124), this activity is separated into two bands, one corresponding to the digital clock frequency (some 3—5 MHz and har-

Table 7. **E** field strength from VDTs in the megahertz frequency region.

Number of VDTs tested	Distance (m)	Frequency range (MHz)	E field strength (V/m)	Reference
>200	At surface	3—10 10—30 30—300	Maximum 0.5 Maximum 0.12 Maximum 0.18	Cox, cited by Zuk et al (133)
2	At surface	20 and 27	“Detected”	Moss et al (80)
2	0.05	13—27	0.05—0.08	BRH (14)
1	0.25	Approximately 10—100	0.005 ^a	Wolbarsht et al (128)
4	0.30	Varies, eg, 3	<0.1	Harvey (52)
1	1.0	30—225	0.0002—0.0006 ^b	Terrana et al (115)
7	1.5	1.5—15	0.001—0.01 ^c	Weiss & Petersen (125)

^a Total for the frequency band 10 MHz—10 GHz, major emission within 10—100 MHz.

^b Average over the frequency range.

^c Six of seven VDT's tested in this range; however, these emissions were not verified as VDT originating (125).

Table 8. **H** field from VDTs in the megahertz frequency region.

Number of VDTs tested	Distance (m)	Frequency range (MHz)	H field (A/m)	Reference
2	0.05	10—100	$1 \cdot 10^{-7}$ — $2 \cdot 10^{-4}$	BRH (14)
1	0.25	10—100	$1.9 \cdot 10^{-6}$	Wolbarsht et al (128)

Table 9. E field strength from VDTs in the kilohertz frequency range.

Number of VDT's tested	Distance (m)	Frequency range (kHz)	E field strength (V/m)	Reference
>200	"Surface"	10—150 150—300	Maximum 1 800 Maximum 600	Cox, cited by Zuk et al (133)
86	"Close"	10—150 ^a	Maximum > 300 35 % > 60 ^b	Zuk (133)
2	0.05	18—200	21—64	BRH (14)
10	0.05	15—125	35—280 ^c	WEAC (14)
10	0.1	10—150 ^a	Maximum 250	Zuk et al (133)
86	"Keyboard"	10—150 ^a	Maximum 7 16 % 5—7 35 % > 1	Zuk et al (133)
1	0.25	Approximately 10 —100	0.225	Wolbarscht et al (128)
86	0.3	10—150 ^a	Maximum 4.4 25 % > 1	Zuk et al (133)
2	0.3	18—200	0.3—2.4	BRH (14) ^d
15	0.3	15—125	2.4—270	WEAC (14) ^d
10 ^e	0.3	15—125	2.4—45 ^e	WEAC (14) ^e
4	0.3	Approximately 16	3—30	Harvey (52)
>200	"Operator"	10—150 150—300	< 2 ^f < 0.6 ^f	Cox, cited Zuk et al (133)
1	1.0	10—100	Approximately 0.001	Terrana et al (115)
8	1.5	15—125	Approximately 0.01	Weiss & Petersen (125)
1 ^g	1.5	Approximately 20	0.005 ^h	Weiss (124)

^a Total range tested was 10 kHz—200 MHz. Emissions assumed by Zuk et al (133) to be confined to the 10—150 kHz range.

^b Percentage refers to number of VDTs.

^c One additional unit emitted >300 V/m.

^d Total for the 1 kHz—10 MHz region, most found in 10—100 kHz region.

^e Those 10 units for which readings were reported also at 0.05 m (14).

^f Inferred, surface field strength "dropped by a factor of at least 1 000 at the position where the operator would normally be" [Cox, cited by Zuk et al (133)].

^g A "typical" VDT.

^h Fundamental frequency. Root-mean-square, all frequencies (10 kHz—1 GHz) = 0.01 V/m.

monics) and the other to the digital signal frequencies (higher frequencies). (This phenomenon has also been indicated in an unpublished memorandum by K Hansson-Mild.)

Measurements of low radio frequency (~ kilohertz) fields

Electromagnetic fields around VDTs in the frequency range 10 kHz — 1 MHz have consistently been detected in a number of investigations. This frequency range corresponds to the horizontal sweep frequency (normally 15—25 kHz) and its major harmonics (ie, multiples of this fundamental frequency) (see tables 9 & 10). In some investigations, at least 95 % of the total field amplitude (all radio frequencies) was accounted for by the fundamental frequency and its five next harmonics (corresponding to the range of some 15 to 125 kHz). This occurrence was apparent for both the **E** and the **H** field (14). Other measurements indicate a wider spread of at least the magnetic field frequencies (95).

The results show an **E** field of between 0.3 and 150 V/m and an **H** field of some 0.05 A/m (at approximately a 30-cm distance).

Measurements of very low frequency electric and magnetic fields

Few measurements have been made in the VLF region around VDTs (see table 11). As suggested by these results, the electric and magnetic fields in this region are comparable to those of the low radio frequency (kHz) region — some 50 V/m (**E** field) and 0.1—0.2 A/m (**H** field) (30-cm distance).

Some comments on the appearance and measurement of electromagnetic fields

The following discussion is (unless otherwise noted) limited to the low radio frequency (kHz) region, due to lack of data on the detailed fields in the other regions.

These measurements were made on a number of different VDTs, with different measuring instruments/procedures and with varying background levels. Thus the considerable variations found between different measurements in each field and frequency region are not unexpected.

Table 10. H field from VDTs in the kilohertz frequency range.

Number of VDTs tested	Distance (m)	Frequency range (kHz)	H field (A/m)	Reference
1 ^a	"Close"	17.1	2.8 (B = 3.5 μ T)	Tell (114)
2	0.05	18—200	0.65—0.70	BRH (14)
1	0.25	Approximately 10—100	9·10 ⁻⁴ ^b	Wolbarscht et al (128)
2	0.3	18—200	0.008—0.036	BRH (14)
43	0.3	15—530 ^c	0.047 (0.003—0.16)	Paulsson et al (95)
1 ^a	"Operator"	17.1	0.06 (B = 0.07 μ T)	Tell (114)
7	0.7	15—530 ^c	0.01 (0.001—0.02)	Paulsson et al (95)
30	1.0	15—530 ^c	0.005 (0.0003—0.06)	Paulsson et al (95)

^a A "typical" VDT.

^b For the frequency region 1 kHz—10 MHz, most within 10—100 kHz region.

^c All frequencies 50 Hz—500 MHz, most confined to the principal (horizontal sweep) frequency and its harmonics.

Table 11. VLF magnetic and electric field intensities around VDTs.

Number of VDTs tested	Distance (m)	Electric field intensity (V/m) ^a	Magnetic field intensity (A/m) ^b	Reference
3	0.03	..	0.097—0.217	Stuchly et al (111)
	0.05	..	0.084—0.131	
	(power off)	..	0.042—0.063	
1	(at yoke)	..	4.019	Stuchly et al (111)
4	0.03	30—65	..	Harvey (52)

^a Normal brightness, root-mean-square (all frequencies — 60 Hz and harmonics).

^b Sum, all frequencies (60 Hz + harmonics up to 420 Hz).

Confounding by background levels

As seen in the preceding discussion, the levels in all ranges (except the E field of the kilohertz region) are below the background levels indicated on pages 20—21. The use of shielded rooms for measurements, while used in several investigations (eg, 115, 128), was not always explicitly stated or inferred. (Verification of a VDT origin of specific signals was, in some investigations [eg, that of Weiss & Petersen (125)], made by the switching of the terminal on and off.)

Variations due to instruments

The capacitive coupling problem apparent with some instrumentation in the megahertz region has already been referred to. No such effect has been discussed for the kilohertz region. It is fairly obvious however that recordings made by different instruments will differ; see pages 22—23 and the BRH report (14).

Variations in video display terminals

The application of the same measuring procedures to different VDT models results in great variations in the E field, as exemplified by the WEAC measurements (14). The E field amplitudes varied between 28 and >300 V/m (at 5 cm) and between 2.4 and 100 V/m (at 30 cm). In the report of Paulsson et al (95) the H field varied between 3 and 160 mA/m for different models.

The following possible VDT design-dependent factors have been examined:

1. The position of the measuring instrument around the VDT was investigated (52). The direction of the maximum field strength is dependent on the position of the flyback transformer (see figure 4). Note, however, that several sources exist for magnetic signals of the the kilohertz frequency (transformer, wires and magnetic coils).

2. The effect of this position is in turn influenced by the degree of shielding. Lining the case of an old VDT with a grounded copper foil caused a dramatic decrease in the measured electric field strength (kilohertz region) (52). Similar effects of shielding were also obtained by the BRH (14).

3. In principle, the design of the magnetic coils around the yoke will greatly affect the electromagnetic fields in the low radio frequency (kHz) and the VLF (Hz) regions. Decreasing the maximum deflection angle causes a corresponding decrease in the magnetic fields.⁴ Such a decrease is however tantamount to lengthening the CRT tube (if the screen size is to be kept constant).

⁴ The exact relationship between the angle of deflection of the electron beam and the magnetic field is rather complex. [See, eg, the book by Grivet (44).]

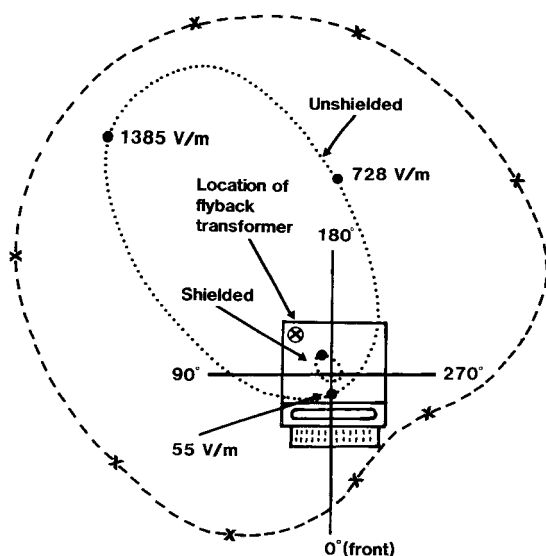


Figure 4. Geometric variations in the electric field (15.9 kHz) from a VDT. Dependence on the locations of the flyback transformer and shielding (52, 75). (—x— = locus of constant amplitude (55 V/m) (distance to VDT surface noted); = polar diagram of field in horizontal plane, 30 cm from VDT surface) (Note: noncomparable scales)

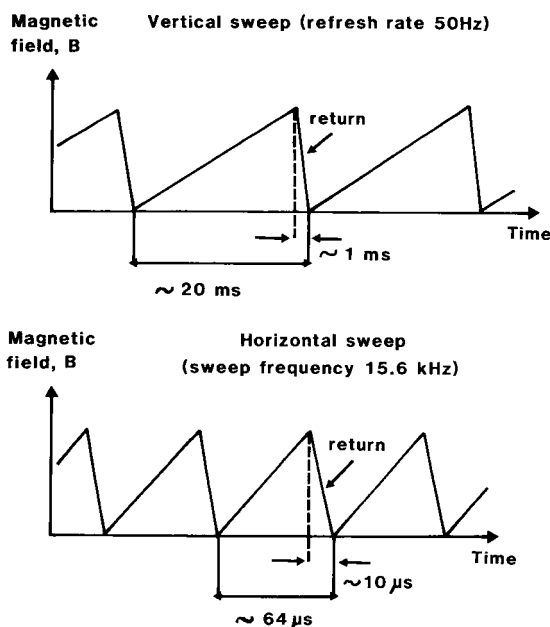


Figure 5. Principal realtime appearance of pulsed magnetic fields used for horizontal and vertical deflections of the electron beam. The real appearance of these fields can be quite complex.

4. Harvey (52) has reported on the influence of the writing mode of VDTs on the measured electric fields. This influence was considerable in the ELF and the high radio frequency regions. Some examples: The ELF amplitudes were directly related to the

brightness of the display. In the megahertz region, (some?) peak frequencies appeared to be “display dependent.” They were generally absent with a “quiescent” terminal. The kilohertz signals were (as should be expected) fairly independent of display parameters.

Realtime dependence of the fields in the kilohertz and hertz regions

The fields in the kilohertz and hertz regions are due to the requirement for electron beam deflection and are thus related to the maximum deflection angle of the beam (as has already been discussed briefly) and to the scanning (horizontal sweep) and the refresh (vertical sweep) rates. Some principal appearances of these magnetic fields are shown in figure 5. The realtime appearance of the total magnetic fields is however much more complex, since the total is formed by several constituent fields of varied location and frequency (95).

With a **B** field (kilohertz region at 30 cm) of 0.07 μT ($H = 0.06 \text{ A/m}$) (see table 10), the time derivative of the field (dB/dt) will be of the order of 10 mT/s during the “return time” (see figure 5).

In the VLF/ELF region, a typical value for dB/dt (from the vertical sweep) is about 0.5 mT/s (30-cm distance).

The range of dB/dt (all frequencies 50 Hz — 300 kHz) has been measured for a number of VDTs (95), ie, 13.5 mT/s (0.3 m, 43 VDTs), 2.3 mT/s (0.7 m, 7 VDTs), and 0.8 mT/s (1 m, 28 VDTs). The range at a 0.3-m distance was 1 to 43 mT/s.

Distance and field appearance

The **E** and **H** fields (kilohertz region) were found to be radially directed from the VDT screen (14). In the report of Paulsson et al (95) the total (all frequencies) **H** field had a varied direction, with sizable components along all three coordinates.

The electromagnetic fields from the VDT decrease quickly with increasing distance (as indicated for the megahertz **E** field and the kilohertz **E** and **H** fields in tables 7—11). The degree by which these fields appear to decrease vary however between VDT models and also between investigators. The 5 cm/30 cm quotient of the **E** field, kilohertz readings from 10 models in one investigation, varied between 6 and 30 [WEAC measurements (14)]. Two of the VDTs were retested with another instrument by the BRH (14), whereupon the quotients found were considerably increased (from 12 to 16 and 27 to 93, respectively). This difference appears to be caused by the varying instrumental sensitivity at varying distances.

In the report of Paulsson et al (95) the **H** field (50 Hz—300 kHz) decreased as about r^{-3} with distance (r), although considerable variations from this value were found for many individual models.

Compliance of emissions from video display terminals with existing standards

In Sweden, proposed occupational standards for radio frequency fields encompass the frequency region 3 MHz—300 GHz. Within this region, field strengths in the band 3—30 MHz should not exceed 140 V/m (**E** field) and 0.4 A/m (**H** field), while the maximum field strengths in the band 30—300 MHz are 60 V/m and 0.16 A/m, respectively (135). These limits are in general agreement with that of, eg, US (ANSI, NIOSH, ACGIH) and international recommendations (IRPA).

The high radio frequency fields around VDTs are orders of magnitude below these standards.

In the 10 kHz to 3 MHz region, the ACGIH has adopted TLVs of 600 V/m (**E** field) and 1.6 A/m (**H** field) (1). These values are somewhat higher than those of the IRPA (the latter however being confined to above 100 kHz). (No Swedish standards exist in this region.) The levels measured from VDTs in this region are considerably below these occupational standards.

No standards exist for part of the low radio frequency and the VLF and ELF regions. An evaluation of VDT emissions in these regions is based on several points: (i) thermal mechanisms are thought to be responsible for many of the effects on biological systems seen after exposure to primarily microwave radiation (130); (ii) the relative energy absorption of radio frequency radiation decreases with decreasing frequencies. [See, eg, the discussion on specific ab-

sorption rates by Guy (48).] Thus the **E** field and **H** field intensities recorded in the low radio frequency and VLF regions are not expected to cause any effect (which depends on thermal mechanisms).

However, resonance frequencies (allowing for nonthermal effects) have been under considerable discussion lately. In such (narrow) frequency bands, specific energy absorption may occur — coupled to specific receiver mechanisms and thus to specific effects of modest intensities. The existence of such frequencies would invalidate the evaluation for that specific frequency.

No such resonance phenomena have (so far) been shown for frequencies and intensities of interest with respect to VDTs. (See, however, some comments on pages 65—66.)

A second evaluation procedure is possible. In the kilohertz and hertz regions, VDT emissions are in general of the same order of magnitude (or lower) than many other ubiquitous devices or environments. Comparisons with television sets have been made, eg, by Harvey (52), Paulsson et al (95), and Weiss (124). Harvey (52) found that, throughout the kilohertz and hertz regions, exposures due to VDT emissions were comparable to those of a color television set (even when allowances were made for an increased viewing distance to the set), while others (95, 110) found levels of the kilohertz magnetic fields to be, for example, 50—100 times lower during normal television viewing when allowances were made for distance (110).

6. Electrostatic fields

Existence of electrostatic potentials on video display terminal screens

Screens of CRT design frequently attain an electrostatic potential when in operation. No explanation of the cause(s) of these potentials and fields have been published, but they can readily be assumed to be dependent on two factors. First, there is the postacceleration potential commonly used in CRT devices to accelerate the electrons towards the screen. This potential is applied to the metal-coated inside of the screen and may amount to 20 kV or more (44). Second, the screen itself should ideally serve as a shield for the field associated with this potential (charge), but this shielding may be imperfect, supposedly due to the limited conductance of the screen itself. [For a brief discussion, see the report of Cato Olsen (17).]

Measurements of electrostatic fields from video display terminals

A few reports on measurements of electrostatic fields from VDTs have hitherto been published. They have been summarized in table 12. When these data are compared, the following three causes must be considered for the varying values:

1. *Differences according to make:* Nylén et al (91) examined a number of VDTs of seven different makes. Two makes exhibited almost no fields, one had a fairly small field, and four had large fields. Similar patterns were also seen in the other investigations.

2. *Differences according to measuring procedures:* Cato Olsen (17) and Nylén et al (91) used the same

Table 12. Measured electrostatic fields from CRT-based VDTs.

Number of VDTs tested	Distance (m)	Electrostatic field range (kV/m)	Fraction of VDTs in this range	Reference
29	0.05 ^a	0—20 20—60 80—140 160—240 45	52 % 21 % 21 % 6 % Mean all	Cato Olsen (17)
400	0.10 ^a	75	Mean all	Nyl��n et al (91)
44	0.30 ^b	<0 0—10 10—20 20—30 11	7 % 39 % 41 % 14 % Mean all	Paulsson et al (95)
4	0.30 ^b	5	Mean all	Harvey (52)

^a Measured without a grounded sheet adjacent to the field mill.

^b Measured with a grounded sheet adjacent to the field mill.

procedure, ie, the placement of a field mill in a central position in front of the screen. The mill was grounded and the field strength was noted. In the investigations of Harvey (52) and Paulsson et al (95) the measuring procedure was supplemented by the placement of a large grounded metal plate adjacent to the field mill (with the field mill sensor in a hole made in the plate). The latter procedure is less vulnerable to distortions of the measured field. The introduction of the large grounded plate will, however, also change the field geometry considerably and cause a substantial decrease in field strength. Therefore direct comparisons between the results of the two procedures are not possible.

3. *Differences according to distance:* Paulsson et al (95) found that the electrostatic field decreased as r^{-1} "close" to the screen, and as r^{-3} at "larger" distances (r) from the screen.

Approximate potential on the screen

In an attempt to eliminate the influence of the measurement geometry, the potential on the screen was calculated; the electrostatic field strength was multiplied by the distance. (See comments in appendix 1.) The results must be regarded with some reserve, due to the inexact potential approximation used and the different measuring procedures used, as presented in the preceding discussion.

The mean calculated screen potential of the different investigations was 1.5 kV (52), 2.25 kV (17), 3.3 kV (95), and 7.5 kV (91). After an examination of the variations in each investigation, all the VDTs could (provisionally) be divided into three distinct groups, ie, a "low" group with screen potentials between 0 and about 1 kV, a "medium" group with screen potentials of about 5 kV, and a "high" group with screen potentials around 10 kV. The high mean screen potential determined for the study of Nyl  n et al (91) can partly be attributed to the large proportions of "high potential" VDTs included in the study and partly to the measuring procedure used.

Electrostatic potential of the operator

Numerous data exist on the electrostatic potential of humans. The potentials of VDT operators have been measured by, eg, Cato Olsen (17) with the same methods that were used to measure the screen potential. Of 78 measurements (on 16 individuals), 47.5 % had a negative potential between -2.2 and -0.2 kV (mean about -0.9 kV), 28.5 % had a potential close to zero (between -0.2 and 0.2 kV), while 21.5 % had a positive potential between 0.2 and 2.2 kV (mean approximately 1.1 kV). Two persons (2.5 %) had a positive potential of 3.8 to 4.2 kV. The overall mean potential was -0.6 kV.

The measurements of Nyl  n et al (91) indicate that the average field of operators is more positive [mean 0.0 (SD 7.02) kV/m] than that of appropriate referents [mean -3.68 (SD 11.72) kV/m].

Electrostatic field between the video display terminal and the operator

A rough estimate of the electrostatic field between the operator and the screen can be derived from the formula:

$$E = (V_{\text{screen}} - V_{\text{operator}})/r,$$

where E = the electrostatic field strength, V = the potential, and r = the distance between the screen and the operator.

With data from Cato Olsen (17), the fields thus calculated vary between $+24$ kV/m and -7 kV/m. (The latter corresponds to an uncharged VDT and a strongly positive charge on the operator.) The field between an "average" screen and an "average" operator (17) would be $+4.8$ kV/m (at a distance of about 60 cm). The VDT/operator situations investigated by Nyl  n et al (91) indicate an "average" field between the VDT and operator of the order of $+10$ kV/m.

7. Sound and noise

VDTs are potential sources of several sonic frequencies, in both the audible and the ultrasound range. This noise may conceivably have some bearing on certain physiological and psychological discomforts.

I found very little information on this subject.

Measurements

The acoustic radiation emanating from VDTs has been measured by the BRH (14) and was reported to be within the frequency range 6.3–40 kHz. The dominant frequencies from the 25 tested VDTs were between 16 and 40 kHz and were related to the horizontal sweep frequency. The noise supposedly originated in the flyback transformer core. However, the frequency used in this transformer is often too high for the audible range, especially that of middle-aged people. It is possible that secondary noise sources (with half the frequency of the transformer) may exist within the VDT units.

The SPLs at about 50 cm from the VDT (in the direction of maximum emission) were within the 30 to 68 dB range (mean 51 dB). In the 16–20 kHz range, the maximum registered level was 61 dB (mean 53 dB) (14). Some measurements confirming these levels have been made by others (Wolf S, personal communication).

The mean SPL of 14 of the 25 VDTs tested by the BRH (14) was 52 dB at the horizontal sweep frequen-

cy with a lower SPL (mean 44 dB) at the double frequency. For five VDTs, the opposite was true, the mean being 47 dB at the sweep frequency and 49 dB at the double frequency. For all these VDTs, the sweep frequency was 20 kHz or lower, while the double frequency was above 20 kHz. One VDT had a higher SPL (51 dB) at half the sweep frequency than at the sweep frequency (44 dB at approximately 35 kHz) (14).

Compliance with standards

Swedish occupational standards limit the SPL at 20 kHz and above to between 105 and 115 dB (relative to 20 μ Pa) (86). At 8–20 kHz, the level is 80 dB. For “single tones” (conceivably the case with VDTs), the corresponding limit is 70 dB (87).

Thus available information suggests that VDTs comply with present standards with respect to dangerous noise levels in the 6 to 40 kHz range. However, the experimental basis for this suggestion is limited to only a few investigations.

A correlation between complaints of noise from VDTs and emotional/mood complaints was noted by Stammerjohn et al (106). It has been suggested that high frequency noise might be a stress factor and that noise from VDTs may cause “sensory overload” (Wolf S, unpublished memorandum). So far, these suggestions have not been substantiated.

8. Display characteristics and readability of text

The information received by the operator of a VDT is derived from that of the screen, subject to the legibility of the screen characters. A number of parameters are relevant to a discussion of discomfort or health effects (eg, asthenopia) and job performance. These parameters have been divided into three groups, related to the oscillation, the structure, and the luminance of the presented symbols. Workroom illumination parameters are included in this chapter, since they are closely interrelated with the display parameters in defining, eg, screen contrast.

Reading performance is discussed as an indication of adverse display presentation only — the rationale being that adverse reading performance will have effects on eye discomfort, stress, etc. [For further dis-

cussion, see, eg, the reports of Bouma (11), Engel (33), Radl (97), Timmers et al (116), and the NRC Panel (94).]

Standards or recommendations are included only as a comparison, to indicate adverse display parameters. The text is not intended as a guide for specific design. [For a discussion of standards, see, eg, the reports of the European Computer Manufacturers Association (34), the Swedish Institute of Standardization (107), and Knave (66).]

The definitions of polarity as used in this review are as follows: positive polarity = dark characters on bright background, and negative polarity = bright characters on dark background. All the presented data have been adjusted accordingly.

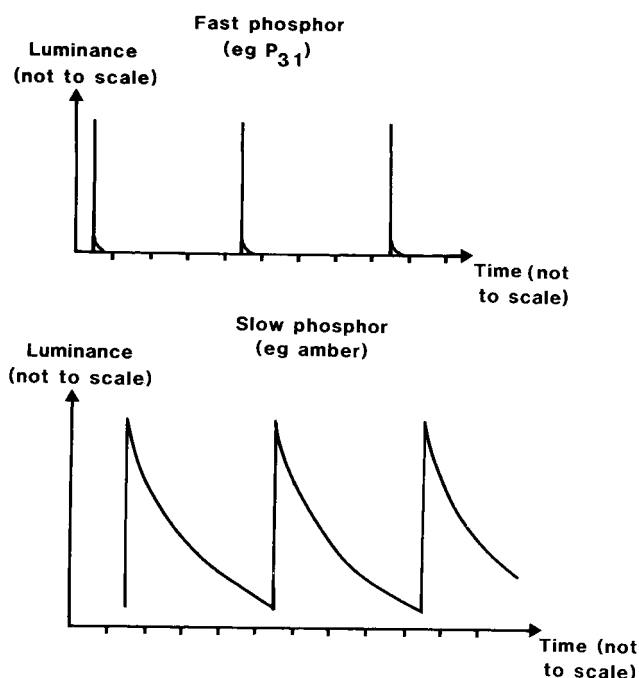


Figure 6. Realtime appearance of a fast and a slow phosphor (in principle).

Time-dependent variables of screen luminance

Pixel illumination rates

As described on page 14, the electron beam in a CRT device sweeps across the pixels, producing an illuminated dot or a line segment.

A typical vertical sweep time of 19 ms (and a return time of 1 ms) corresponds to a refresh rate (repetition of each pixel irradiation) of 50 Hz. Refresh rates of 56–77 Hz (typically 60 Hz⁵) and 48–81 Hz (typically 50 Hz⁵) have been noted by the BRH (14) and the Swedish SSI (95), respectively.

The horizontal sweep frequencies varied considerably in the BRH (14) (between 2 and 35 kHz, typically 15–20 kHz) and SSI (95) (15 and 53 kHz typically 15–25 kHz) investigations. The return times varied between 2.8 and 10 μ s (mean about 6 μ s) (95). A horizontal sweep time of 54 μ s (line frequency 15.6 kHz) corresponds to some 230–300 lines/frame (with some time allowed for return time, etc). With a character matrix of 7×9 pixels and 80 characters/line, the passage time is about 0.1 μ s/pixel. [The information frequency needed for beam modulation (gate potential, figure 1) is then on the order of 10 MHz.]

Oscillation of pixel lumination

The realtime appearance of the pixel lumination is shown in figure 6, both for a fast and a slow phosphor. Phosphor decay times (from 100 to 10 % of maximum lumination) vary considerably with the

phosphor, and they also vary considerably between different investigations.

CRT decay times range from extremes of 160 ns (P_{46} — used in the Flying Spot Scanner) to 140 ms (P_{158} in Medium Persistence Yellow). Typical decay times for VDT phosphors are 50–100 μ s (Hansson G, Versal AB, personal communication), although more persistent phosphors are also in use, decay times of, eg, 1.5 ms (P_{43}) (Hansson G, Versal AB, personal communication) to > 20 ms (“amber”) (Nylén P, personal communication). In the report of Grandjean (41) decay times varied between 150 μ s (P_4) to 400 ms (P_{39}). A P_{22G} phosphor has a decay time of 60 μ s [according to data of the Clinton Corp (Hansson G, Versal AB, personal communication)] and a decay time of 6 ms [according to data of the IBM Corp (41)].

Conceivably, the large variations in reported decay times may be due to the rise time of the detector — which determines the top luminance and thus the decay time. Unfortunately, the rise time of the instruments used have not been reported. (See figure 7 for comments.)

The degree of oscillation has also been characterized by uniformity figures, ie, the quotient between the darkest and the brightest phase of the cycle. Thus, a low uniformity figure corresponds to a “high” degree of oscillation. [These measurements — in contrast to those of decay times — are performed in an illuminated workroom and are thus related to both the brightness control and the workroom lighting (67).]

The uniformity figures of single dots presumably correspond to the oscillation experienced by the fovea (67).

⁵ Net frequency in the US is 60 Hz as opposed to the European 50 Hz.

Top luminance

The measurement of the top luminance (luminance during steady state — ie, during excitation) requires instruments capable of recording luminances within 100 ns. Fellmann et al (35) examined eight VDTs. Two “extreme” VDTs were described — mean luminance 40 and 38 cd/m^2 and a top luminance of about 75 and 700 cd/m^2 . The decay times (100 to 10 % of the recorded luminance) were >20 ms and about 2 ms. These recorded decay times are in excess of those reported, eg, by the Clinton Corp (Hansson G, Versal AB, personal communication).

My own calculations, based on mean luminances of a P_{31} phosphor of 50 cd/m^2 (during the 20-ms cycle) and P_{31} decay functions with half-lives of 12 and 56 μs (recorded with a moderately fast detector), indicate that the top luminance may be very high, exceeding 10 000 cd/m^2 . So far, these calculated data have not been verified by actual measurements of top luminance.

The blitz phenomenon

Operators working with positive image screens, and also viewing customers or other objects above the screen (eg, in banks or travel bureaus), sometimes perceive a brightly shining horizontal line when their gaze moves down the screen. A tentative explanation for this phenomenon (“blitz”) has been offered (90). The operator’s (vertical) gaze velocity is similar to the vertical sweep velocity of the VDT. Thus the oper-

ator’s gaze may follow the “front” of illumination down the screen, and therefore a luminance considerably higher than the average screen luminance is seen.

This blitz phenomenon was observed with a fast phosphor (P_{31}) but not with a slow one (amber). This finding is in accordance with the fast phosphor’s higher contrast between top and mean luminance (90) (see figures 6 & 7).

Flicker

The variations in luminance during one refresh period can be perceived as a flicker. In principle, increasing luminance by a factor of 10 will increase the highest frequency at which flicker is noticeable by 10 Hz (6, 94). Critical flicker fusion is defined as the frequency at which (with 100 % modulation) no flicker is recognizable (65).

In a field survey (20) 12 % of the examined VDTs showed flicker. In another survey, no flicker was observed on any examined screen. However, 68 % of the operators complained about flicker (106). Flicker perception is however dependent on a number of other parameters, eg, polarity, screen luminance, room illumination, degree of oscillation, and contrast, as well as on whether foveal or perifoveal vision is utilized and on individual sensitivity (41, 94, 106). Experiments done by Nishiyama et al (89) suggest that critical flicker fusion declines after exposure to 30 or 60 Hz.

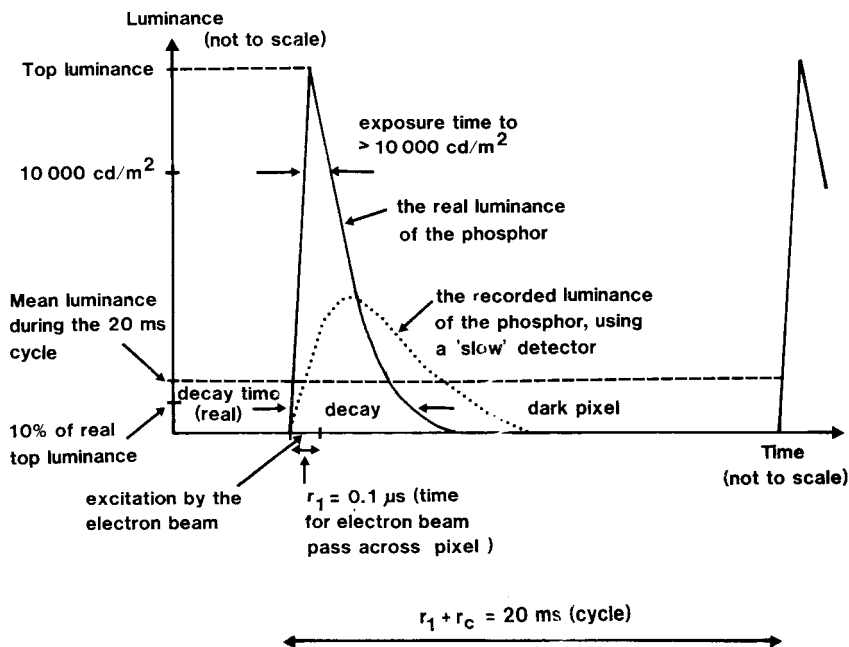


Figure 7. Detailed realtime appearance of a fast phosphor and the detected appearance as measured by a “slow” detector (in principle). Note that the recorded decay time of the detector will be longer than the real decay time. Reported decay times in the literature are thus (partly) attributed to the detector and not (primarily) to the phosphor.

Low frequency modulation (periods of several seconds) of the flicker may appear due to the oscillation of room lighting. A fixed synchronization between the CRT refresh rate and that of the general power supply — especially with a 180° phase shift — may eliminate this phenomenon (45).

Flicker may adversely affect the visual comfort of the operator — and thus possibly cause asthenopia symptoms. Effects on visual reading performance per se has not been established (94). Visible flicker may cause an adaptive overload of the eye, since the retina will be repetitively overexposed. It has been suggested (67) that nonperceived flicker may also have some adverse effects on the retina, but this possibility has not yet been confirmed.

Flicker should not be observable, according to present standards.

Jitter

Time variation in the position of display characters can sometimes be observed. This phenomenon is due to improper variations in the magnetic fields used to deflect the electron beam.

These time variations may have a frequency of 0.03—0.5 Hz. Of eight examined VDTs, considerable jitter was found in four (35). According to subjective evaluations three VDT makes had good stability, and the other five showed “continuous trembling.”

Jitter is in principle harmless, but it may be irritating and tiring. Jitter should not be observable (17) or exceed 0.7' (0.1 mm at a viewing distance of 50 cm) (34).

Afterglow

Some phosphors, notably those used for radar display, have a considerable afterglow, ie, the character luminance decreases very slowly and is perceived for several refresh periods after the corresponding pixels are no longer irradiated. With fast phosphors (normally used for VDTs) this phenomenon is not seen.

Structure of screen characters

Characters and symbols

The character image may be composed of either strokes or dots (see figure 8). Examples of both image systems occur frequently.

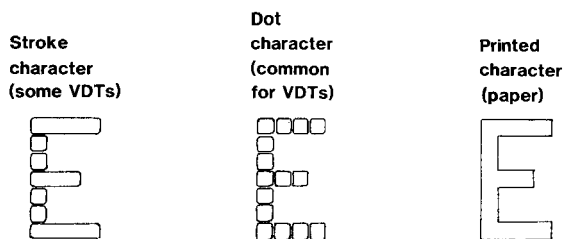


Figure 8. Different types of character structure.

The information processing techniques may be different in stroke versus dot characters (94). Dot matrix presentation has been claimed to be superior for legibility (35).

The fonts used in VDT representations are quite different from many established fonts in printed text. There may be a conflict between acceptability (expected notions of character appearances), identifiability, and distinctness. Optimal font design is of particular importance for noncontextual presentations (11).

Resolution and character matrix

Visible raster structure decreases legibility. This problem will dictate a minimum of scanning line density, eg, 729 or 1 029 (obviously depending also on screen size) (94).

Matrix sizes vary from 5 × 7 to 7 × 9 or higher, etc. Increasing the matrix from 5 × 7 to 7 × 9 will increase reading performance (14 % improvement in reaction time, 10 % decrease in errors in one study) (53). A 7 × 9 dot matrix is necessary for the presentation of both upper-case and lower-case letters (16). Suggestions for an 11 × 14 matrix (for the symbol H) have been made (107).

The optimum size of the characters is dictated both by sufficient size for identification and by their not being too large, since otherwise too few characters can be read simultaneously in the fovea [see, eg, the report of Bouma (11)]. The character height has an optimum for reading performance of some 20—28' (65). Standards have been suggested (107) for 20' symbols — corresponding to a height of about 3.8 mm (of the symbol H) at a reading distance of 60 cm. The symbol width should be 50—60 % of the symbol height (excluding the letters I, l and the numeral 1).

With somewhat less stringent standards than those suggested by the Swedish Institute of Standardization (107), eight VDTs were examined as to symbol characteristic parameters (matrix size at least 7 × 9, symbol height 3.3—4.1 mm (0.7-m distance), and symbol width 50—75 % of height). Only two VDTs fulfilled the standards, while four failed on one of the parameters. The remaining two failed on two parameters (35). [None fulfilled the standards suggested by the Swedish Institute of Standardization (107), and only one complied with more than one parameter requirement].

Spacing and legibility of words

Acceptable symbol line spacing is determined by the eye saccade movements. The distance between symbol lines should increase with increasing line length, with a minimum of a 2° return trajectory of the line saccade (line angle). To meet this requirement, vertical orientation of a full page screen (eg, with a 4:3 aspect) or a two-column presentation in horizontal orientation can be used (11).

Suggestions have been made for the spacing between two symbols (in the same word) to be 20–30 % of the symbol height, for the spacing between words to be 50–70 % of the symbol height, and for the spacing between lines to be at least 170 % of the symbol height (107).

Again, less stringent standards were evaluated (space between symbols 20–50 % and space between rows 100–150 % of symbol height) (35). Only two of eight VDTs fulfilled one of the parameter requirements. (None fulfilled both.) In a final evaluation, three of the eight VDTs tested were judged to give “good” legibility according to the standards used. Subjective evaluations (made by 10 subjects) concurred (35).

Geometric variation

According to the European Computer Manufacturers Association (34) and the Swedish Institute of Standardization (107) the relative image distortions should not exceed 1 % of the corresponding height or width.

Sharpness and blur

In principle, luminance is not constant across a single dot; instead it has a variable luminance distribution across (any) scan path of the dot. Techniques for evaluating sharpness include edge response and modulation transfer function.

The modulation transfer function is the fourier transform of this line spread function. It is a useful concept for the analysis of contrast, resolution, jitter, etc (5, 94).

With the use of the edge response technique, the sharpness of the characters can be characterized by the slope of the luminance across the character contour. This slope has been measured for five VDTs of different makes with negative polarity (35). At maximum luminance, the slopes varied between 63 and 350 $\text{cd/m}^2\text{,mm}$ and was between 37 and 127 $\text{cd/m}^2\text{, mm}$ at the “preferred” luminance. A VDT with “good” characteristics had a luminance slope of 116 $\text{cd/m}^2\text{, mm}$, while a “bad” VDT had a slope of 37 $\text{cd/m}^2\text{, mm}$ (at preferred luminances). Sharpness was “poor” according to subjective evaluations (10 subjects) for two of the eight VDT makes (35).

Blur affects accommodation processes (see page 50).

Luminance of screen information

Polarity and general luminance

Negative polarity means light or irradiated characters on a dark or nonirradiated background. The opposite is positive polarity. A positive polarity screen will have an average luminance of 2–2.5 times that of a negative polarity screen (94).

If the adaptation of the eye is determined by the average luminance, a positive polarity screen will imply a somewhat higher (about 15 %) visual acuity. However, this assumption has been criticized, and it has been suggested that adaptation is not based on the average, but on the higher luminance (94).

It has been suggested that transient adaptation glare may cause transient changes in pupil size when positive and negative polarity areas (document versus screen) are viewed alternately. This suggestion was based on experimental results obtained with a slide projector. However, the study was criticized on the grounds that the response may have been due to the brief dark periods between the slides (94). Furthermore adaptation is presumably sufficiently fast (on the neural level) for the operator not to notice the change (16).

In general, there are other possible benefits of higher luminance (increase in visual depth, increasing visual acuity due to less contrast with surroundings, etc). These conclusions have been drawn on the basis of research on paper presentation; similar research results on VDT screen presentation is somewhat limited (94).

Positive polarity will reduce the appearance of discomforting glare and reflections (6, 34, 98). It will therefore reduce the measures necessary in workstation design and require less stringent workroom lighting restrictions.

In an experimental set-up, positive polarity gave a higher test performance (letter transcribing), a higher visual comfort rating, and was preferred by 19 of the 24 subjects (2 having no preference and 3 preferring negative polarity) (97). Similar findings were made by Bauer & Cavanaugh (6), ie, there were lower error rates with positive polarity. In this experiment, 22 of the 23 subjects preferred positive polarity.

The flicker threshold will, however, be increased with an increasing average luminance. A refresh rate of 50 Hz is not acceptable for positive polarity (107). That of 100 Hz has been recommended (6). Accordingly, many existing VDT and CRT devices with 50 or 60 Hz refresh rates may be unsuitable for positive polarity. It should be noted that some VDTs have been provided with options as to polarity. Such an option is clearly inadvisable if the refresh rate is low (50 or 60 Hz).

Character stroke width should be somewhat wider for positive polarity (34).

Workroom illumination

Proper illumination is necessary for the reading of both screen and source documents. Recommendations for workroom illumination show however considerable variation. For general office environments, recommendations vary between 75 and 1 600 lx. For VDT workplaces recommendations are considerably lower, often in the 100–500 lx range (106). Thus there is an apparent conflict between illumination for

source documents and for the screen. This problem is often solved by a low workroom light level and additional lighting at the source document.

NIOSH recommendations are 300–700 lx (without source documents) and 500–700 lx (with source documents) (79).

Subjects allowed to adjust their workroom illumination normally select illuminances of 200–600 lx; 500 lx can be recommended for negative polarity, with 600–700 lx for positive polarity (53).

Coe et al (20) found workroom illumination to be <250 lx (31 %), 250–500 lx (63 %), and >500 lx (6 %). Higher levels were determined in the study of Stammerjohn et al (106), a median of 500–700 lx. Furthermore the majority of the subjects (53 % and 63 %) were satisfied with the workstation and background illumination.

In data entry work, source illumination was 550 lx, compared to 430 lx for work in a conversational mode, and 500–800 lx for non-VDT workers (67).

Contrasts between the screen and surroundings

There are several definitions of contrast, for example, the ratio $C_r = L_o:L_b$ or $C = (L_o - L_b)/L_b$, where L_o is the object luminance and L_b is the background luminance (9, 34). The latter definition is recommended. The data that follow however are presented as they appear in the literature, thus often as the ratio C_r .

Contrasts between the screen and surroundings should be 1:3 for the near field and 1:10 for the far field (24). However, less restricted limits (up to 1:20) show similar reading performances according to one study (53).

In the study of Coe et al (20) 33 % of the worksites exceeded the near-field recommendation 1:3 (screen:source). For screen:background and a near field, 54 % exceeded this recommendation, 24 % exceeded the far-field recommendation of 1:10. The near-field contrasts in the report of Fellmann et al (35) varied between 1:1 and 1:28 (negative polarity). Screen:source contrast varied between 1:8 and 1:25, while screen:frame contrasts were between 1:1 and 1:8. Unsuitable colors on VDT boxes were frequently found and could affect visual performance (35).

Very high contrasts were noted by Läubli et al (67), ie, 1:21–26 for the near field and about 1:300 for the far field.

A wider frame around the VDT can bring improvement under unfavorable conditions, especially with continuous shading of the frame (97).

Reflections

Reflections can be either specular (mirror-like) or diffuse. Here only specular reflections are considered.

The virtual image which may appear is located behind the screen. For example, reflection of the opera-

tor's face will typically lie about 22 cm behind the screen. Different accommodation levels are, in principle, required for the screen text and the image; this circumstance may be annoying and cause discomfort (94).

Discomfort glare

Glare can be defined as discomfort glare or disability glare; the latter is discussed elsewhere. Discomfort glare causes discomfort without immediate effects on reading performance. Discomfort glare may be direct (from bright luminance objects) or reflected (from, eg, keyboard keys) (106).

In one field survey, 46 of the 53 workstations investigated had potential discomfort glare due to luminance levels of up to 2 100 cd/m² from windows or lighting. In the same study, 80 % of the VDT operators versus 62 % of the referents reported glare problems (106).

Brightness of irradiated screen areas

For negative polarity, adjusted character luminances vary between 7 and 160 cd/m² (12, 41, 47). The preferred adjusted character luminance in one field study was 31 cd/m² (range 23–42 cd/m² — with the lower values obtained from a VDT with a fast phosphor (12).

For positive polarity, suggestions have been made for adjusted background luminance of up to 170 cd/m² (107).

In one field study (106), 70 % of the VDT operators complained about character brightness.

Screen contrasts and disability glare

Reflected diffuse glare determines the luminance of the nonirradiated screen areas (background in negative polarity, characters in positive polarity).

Luminances of some 1–50 cd/m² have been reported. For the higher range, there would be a reduced contrast and disability glare, ie, glare directly interfering with reading performance (35, 41, 53, 106).

Character:background contrasts were 2:1 among data entry workers and 9:1 among workers using a conversational mode. The latter type of work apparently led to the operator adjusting the controls to predominantly screen viewing (67). Other field studies show varying contrasts (range 2:1–30:1) (41, 53, 103).

A VDT with “good” characteristics had a screen contrast of 0.13 ($C_r = L_o:L_b$), while a “bad” VDT had a contrast of 0.43 (preferred luminance settings) (35). The preferred contrast also increases with decreasing background luminance, as well as with decreasing room illumination (53).

The contrast between the background luminance “near” a character and that of the character itself was determined (for the letter U) for some VDTs.

The "near" background luminances were between 17 and 82 % of the character luminance for maximum luminance and between 13 and 45 % for preferred luminances (35).

The visual reading field is dependent on the contrast. Low contrasts have no effect on foveal word recognition, but have a major impact on parafoveal word recognition. For a contrast of 0.90, about 80 % of the words were correctly recognized, compared to less than 50 % for a contrast of 0.12. (Positive polarity, contrast defined as $C_+ = (L_B - L_C)/L_B$, L_B = background, L_C = character luminance) (11). The visual field extension may be of importance for contextual reading. Similar results have also been reported by Timmers et al (116), in which both errors and response times increased with decreasing contrast. These studies were performed with paper documents.

Campbell & Durdent (16) supported the use of a broad range of contrasts, adjustable for individual preference. The main argument was that "almost full visual acuity can be achieved over a wide range of contrast [p 177]."

In one field study (106), 62 % of the VDT operators complained about screen brightness. Reflected glare was present in 17 % of all workstations at a level sufficient to make reading difficult, since the contrasts between bright and dark areas were considerably reduced.

Screen color

There are few definite data to support the choice of one phosphor or screen color over others (49, 94, 99), and, despite some general and rather vague suggestion of green-yellow as the best, this issue is often considered secondary to other display parameters (94, 99). The possible impact of phosphor color on, eg, screen contrasts should be considered (116). Color filters are not recommended (97).

Most phosphors used for display purposes have a yellowish green color, during both steady state (excitation) and decay. Some common phosphors have a white color (eg, P_4 , P_{40}), and orange or amber colors also occur (94, 95).

The use of multiple colors for ease of scanning is increasing, but the designs have not always been optimal. Different colors should be used to increase proper emphasis. For example, red has a stronger emphasis than green, and should thus be used only for words important for the scanning process. The use of colors for information purposes is seldom optimal, since man's color discrimination ability is rather limited (33, 97).

Some results indicate that traditional colorimetry may not be fully compatible with the oscillating character of color emissions from VDTs. There may be discrepancies between measured and perceived

colors. The implications of this possibility are not clear. [For additional discussion of this subject, see the report of Tarrant et al (112).]

Conclusions

Oscillation

The oscillating nature of the screen luminance is probably relevant to eye discomfort. Explicit parameters (decay times, top luminance, etc) are not well defined at present however.

Flicker and jitter are important comfort parameters, and the frequency at which flicker is perceived is an important design criterion. A number of other parameters, both display- and operator-dependent, influence this critical frequency. Increasing screen illumination will, eg, increase this frequency.

Structure

The character construction of dots (or raster lines) and their exact relationships are important for character recognition and text readability. Detailed standards or recommendations exist.

Sharpness is probably of major importance for eye comfort (possibly for accommodation processes). Sophisticated techniques for evaluating sharpness are available, but few results have as yet been reported.

Luminance

Positive polarity (dark characters on a light background) has been suggested to be better than negative polarity due to several (interdependent) factors, ie, less adaptive changes, increased visual acuity, less contrast with surroundings, less occurrences of glare and reflections, the possibility of higher room illuminance, less restriction in workstation design, better reading performance, and greater popularity with operators.

Positive polarity VDTs demand a higher refresh rate however to avoid flicker, and some other display parameters may also have to be modified.

Although some of the studies can be criticized as not being conclusive (especially the studies on adaptation changes), the majority do indicate improved work conditions, job performance, and operator satisfaction with positive polarity. Furthermore, although these studies have been criticized, I am not aware of investigations indicating that negative polarity has similar advantages.

Workroom illumination, brightness of irradiated screen areas (characters or background, depending on polarity), and the workstation geometry determine contrasts and disability glare, which are of importance for comfort. Reflections and discomfort glare are other parameters determining comfort.

9. The operator and workstation design

A number of characteristics of the operator have been shown to influence the incidence of reported health effects of VDT operators. The differences between male and female reporting are obvious in some investigations, but other characteristics may also be of importance.

The physical characteristics of the individual operator are also of importance for workstation design. In this chapter the physical design of display, chair, keytable, and desk is briefly reviewed as pertinent to discussions on VDT situations. Although recommendations for these parameters are mentioned, the text is not intended as a guide for workstation design. Instead recommendations are mentioned primarily for comparison with data from field surveys. Detailed recommendations have been given in several reports (22, 34, 55, 77, 84).

For workstation lighting design, see pages 31–33.

Operator characteristics

Sex

In Canada women constitute some 40 % of the total workforce, but up to 60–70 % of the workers in jobs affected by the introduction of VDTs. These jobs include clerical workers, typists, secretaries, telephone operators, bank tellers, and reservation clerks — all jobs for which women form a large majority of the workforce (113). Similar relationships have also been found in other countries.

This predominance of women in VDT workplaces is apparently not true, however, of newspaper offices. In the *Baltimore Sun* study (102), 55 % of the VDT operators were males and 45 % females. In a larger field survey of several newspaper premises (84), 505 men and 542 women participated; 81 % of the men ($N = 409$) and 67 % of the women ($N = 363$) were VDT operators.

The type of work may, however, be quite different. In the *Baltimore Sun* study (102) women were more often found in data entry and clerical VDT work. In another field study (58), 94 % of the data-entry workers were female, and only 50 % of the females did a type of work involving interactive communication.

In another investigation (123) it was noted that women (as a group) had less education and a lower position in the organization, that fewer were “specialists,” that they included more part-time workers, worked longer hours per day at VDTs, and had longer work periods between breaks. Women reported being less satisfied with their jobs, experienced fewer possibilities in using skill, initiation and work planning, had less job variation, had less over-

view as to the relation between their jobs and the end “product,” had less influence on the organization, had more somatic troubles, and worried more over the possible health risks of their work. They did, however, show higher satisfaction with their (general) work environment.

Age and eyesight

There are no general data on the age of VDT operators. Specific data are (when appropriate) referred to in discussions of specific field studies. As indicated in the investigation of Smith et al (102), VDT operators’ age range may include the full working age range. For their study, the mean age was 39.1 years, and the range was 18.8–64.4 years.

The age of the operator may have a significant influence on several health parameters. [See, eg the report of Sauter (101).] One such factor is the presence of presbyopia, necessitating the use of bi- or multifocal glasses.

Some impairment of visual ability (glasses not used or incorrect glasses used) may make VDT work more strenuous. Recommendations for a visual examination have been made if such troubles are indicated (55, 84).

Provisions for VDT work in Sweden, including demands for recurrent eye examinations (and prescriptions for glasses when necessary) of VDT operators are being considered by the National Board of Occupational Safety and Health.

Dimensions

Some investigators have used existing standard body dimensions to estimate, eg, viewing distance and viewing angle from data on workstation configuration [see, eg, the report of Murray et al (84)]. Examples of body dimension, applicable to the US civilian population (extrapolated from military data), can be found in the report of the NRC Panel (94). These data include suggestions for converting “erect sitting” measures to normal or more frequently adopted measures (94), as well as the 5th and 95th percentiles. These latter figures are to be used in calculations.

In an experimental set-up with adjustable display (height, distance, and tilt) and keyboard (height and distance), the subjects had full freedom (within the mechanical limits) to adjust the workstation configuration for maximum comfort. The position of the eyes of these operators were compared to eye position of “statistical subjects” derived from anthropometric data based on the subjects’ height but with a standard posture. The (real) subjects tended to have their eyes about 10 cm closer than the “statistical” subjects (13).

Electrostatic charges

Electrostatic charges were discussed in conjunction with the electrostatic field from the VDT, on pages 25–27, and also briefly in connection with humidity, page 37.

Personal characteristics — Smoking, exercise, etc

Theoretically speaking, personal habits may possibly influence symptoms experienced during VDT work. The report of the Health and Safety Executive in London (55) mentions the use of medication, especially psychoactive drugs, as a possible confounder for certain eye symptoms. One suggested example is drugs that may slow eye movements. Interference may be caused by the wearing of eye and face make-up, possibly related to eye or skin problems.

Unfortunately, I found few explicit data on the personal characteristics of VDT operators in the literature. Bolinder (10) reported a field survey of hospital personnel (almost all female) using VDTs. Among the VDT users (>8 h/week), smoking was more common and physical exercise less common than among those who used VDTs occasionally (<8 h/week) or not at all.

Duration of the work

The time, hours per week, spent by operators at a VDT workstation is obviously dependent on a number of factors, and it is impossible to generalize. In one field study of a newspaper (102), the mean worktime was 21.7 h/week, with a range of 1–64 h/week. It should be noted that the time spent at a VDT workstation may not correspond to the time actually spent working with the VDT. For example, the actual time spent viewing the VDT may be short in certain types of jobs (eg, data entry). (Some data on viewing times are given on page 41.)

With the present fast introduction of VDTs in many workplaces, the majority of present operators have not had too many years' experience working with the equipment. Data of Smith et al (102) will serve to illustrate this point. The mean length of employment (all subjects) at a newspaper was 9.3 (range 0.2–40.3) years, while the average time spent working with VDTs was 3.8 (range 0.1–9.2) years. Thirty-nine percent of the VDT users had used a VDT in previous jobs. (The study was published in 1982.) In a field study (10) of VDT operators in a large hospital, the majority of workers had less than five years' VDT experience, while a small group (6 %) had worked more than 10 years with VDTs. (The report appeared in 1983.) (Data in other studies showing differences in attitudes according to the number of years of VDT work should be checked for, eg, different types of VDT work, as this factor may have a strong confounding effect.)

Education

Few studies have explicitly given data on the education levels of VDT workers. The education levels are presumably closely correlated with the type of job performed (ie, differ, eg, between data entry and professional jobs), although large variations are to be expected between different types of workplaces.

In the US newspaper study already mentioned (102), about 70 % had at least a college level education. Furthermore people with lower education were primarily found in the "eyes-fixed mode" of work (data entry or clerical).

Operator's position at the terminal and workstation design

Viewing distance

Viewing distances and viewing angle (considered with reference to the horizontal direction) have been estimated both by direct measurements and by comparison of workstation measures with general anthropometric data. (As has already been indicated, the latter procedure may possibly introduce overestimates of the viewing distances.)

In general the viewing distances are longer between the operator and the screen than between the operator and the source documents. Mean values in the literature vary between 43 and 88 cm for eye-to-screen distances and between 47 and 53 cm for eye-to-document distances (58, 70, 84, 91). In one experimental study (13) keyboard distances were adjusted by operators to be about 11 cm shorter than screen distances from the eyes, with eye-keyboard distances of 50–52 cm.

The viewing distances vary considerably depending on the type of work, the adjustability of workstation configuration, etc. In one field study (58) movable terminals changed the distances in comparison to those of built-in terminals (62 versus 43 cm for eye to screen, 47 versus 53 cm for eye to document) when the mode of work was one of interactive communication. For data entry and movable display, the distances were 58 cm for eye to screen and 48 cm eye to document. In simple data collecting, the viewing distances were 46 (eye-screen) and 45 (eye-document) cm. In data ciphering and collecting, the viewing distances were 88 (eye-screen) and 50 (eye-document) cm (70). Note that the last type of work included more time looking at the screen, but also a large fraction of the time looking "elsewhere."

In general, individual variations in viewing distances were considerable. Variability in both eye-screen and eye-document distances were less for data entry work than for the conversational (interactive communication) mode (102). Within data entry work, individual variability showed a tendency to increase with data ciphering and collecting compared to simple data gathering (70). (Both modes of work can be described

as data entry, but with important distinctions, discussed later.) Viewing distances (and also time variations in these distances) have been shown to decrease as work speed is increased (in general) (70).

Murray et al (84) found small differences also in the viewing distances (computed from anthropometric data) between men (longer) and women (shorter). Similar small differences were also found by Nylén et al (91) (observed).

Viewing angles (computed from a field study) were examined by Murray et al (84) and found to vary between 0 and $>30^\circ$. Men usually had a 21 to 30° angle, while women tended to have somewhat smaller ones (but generally within the 10– 30° range). In an experimental setup, the viewing angle (as adjusted by the subjects) was 17° (mean) (13).

Recommendations for viewing distances are generally found in the interval 45 to 50 cm, with viewing angles of 10– 20° (84), but somewhat wider recommendations have also been given (34). It is apparent from the data presented that many workplace situations do not conform to these recommendations. The variations may be due to several factors, such as restraints imposed by the equipment, task requirements, individual requirements (eg, eyesight problems such as presbyopia), or individual preferences.

Work posture

No ideal sitting posture can be defined. The possibility of changing posture is of paramount importance. Nevertheless, some general recommendations can be given. The upper arms should be able to hang vertically, and the elbow angle should be less than 90° . Wrists should not be flexed more than 20° . The head should be inclined downwards up to 20° (viewing angle) and should not need to be turned frequently. Upper legs should be horizontal, with lower legs vertical and feet placed firmly on the floor (34, 84).

In one field study of VDT workers (58) the neck and head angle varied between 55 – 61° (VDT) and 58° (non-VDT typist), with lateral head rotation of 8 – 12° versus 19° (typist). These figures reflect the more convenient placing of documents in data-entry work. The ulnar abduction (wrist flexing) was 9 – 20° (VDT) and 17 – 21° (typist).

A factor analysis of the data (58) indicated that (i) an increased viewing distance led to arms more lifted and stretched, turning of the head, and a decrease in the lateral bending of the hand and (ii) reduced leg room led to a slanting position and thus the reclination of the trunk increased and viewing distances were longer.

Conversational VDT workers had more lateral head rotation than data entry workers (58). In general, considerable variations have been found in the postures of operators with different worktypes (102).

In analyses of differences between different types of work, it is noticeable that traditional typists have

more extreme postures with respect to arms and hands than VDT workers do. The lateral head rotation is higher for typists [in apparent contradiction to other observations (127) that traditional typists seldom move their glance from document to keyboard to paper copy, while data entry workers do]. This difference is explained by the fact that typists have their body oriented towards the keyboard (arm position) but their head towards the document.

Furthermore a comparison has been made between simple data collecting and data ciphering and collecting. The former group had larger homogeneity of posture than the latter. The average number of observed posture variants (during the observation period) was 2.6 versus 13.6. Immobilization was not total in either group, but it was clearly higher in the simple data collecting group. This difference was presumably due (i) to the simple data collecting group's predominantly glancing at a single element (document) and spending less time looking "elsewhere" and (ii) to the higher work speed of this group (70). (See also page 41.)

Design principles

Keyboard, desk and document placement. Keyboard and desk height is important for hand positions (not too high) and for leg room (vertical position of lower legs). Recommendations for keyboard height above the floor vary somewhat, but they are generally confined to the 72–79 cm range (about 72 cm for table height), and should be adjustable. A palm rest should be included (34, 84).

These recommendations have not frequently been followed in workplaces investigated in field surveys. In the study of Murray et al (84) keyboard height varied between 72 and 87 cm, with 51 % in excess of 79 cm. Palm rests were not always provided (58).

Keyboards should not be too high and should be movable (34, 58). In a field study (101) of several offices there was a strong association between the movability of the keyboard and viewing angle (mean 20° viewing angle with movable keyboards versus mean 34° angle with keyboards attached).

The dimensions of the key top should be 12–15 mm (square) and at least 100 mm² (nonsquare). The distance between keys should be about 19 mm. The distance the key should move downwards should be between 0.5 and 8 mm (34).

Eight VDT makes were evaluated as to certain keyboard characteristics (height above desk 30–50 mm, degree of reflection of keys and degree of reflection of keyboard box, both 0.2–0.5 (ratio lower:higher luminances). Only one make fulfilled all the requirements, while two more were well designed "on the whole" (35).

Chair. Seat height is also of importance. There should be adequate leg room, and body weight should be distributed at the buttocks and not at the thigh. Ad-

justability of seat height is strongly recommended. Similarly, a sufficient and adjustable back support is essential for good lumbar support (22, 94). Normal seat heights are about 42 to 50 cm, with 18 to 30 cm to table top (34). The possibility of adjusting the seat angle has been recommended (43).

Display. Display position is guided by the recommended viewing angle of 10–20°, the viewing distance, and the normally preferred perpendicular position of the display versus the line of sight. These factors in turn require the display site to be adjustable, with tilts between some –3° to +15° (from vertical). Height adjustments may also be desirable (34).

Adjustability of the display position in an experimental set-up (13) resulted in the display being placed some 11 cm further than the keyboard from the eyes, with a tilt of some 10°.

The recommended vertical orientation of the screen is not found in many screen designs. Most

screens vary between 15 and 20 cm in height and 20 to 25 cm in width (41). Of 45 screens investigated by Paulsson et al (95), three had a vertical orientation, with an aspect of 1.28 (mean) [recommended value 1.33 (11)]. The 42 horizontally oriented screens were between 18 and 30 cm wide and between 11 and 22 cm high. The aspect (horizontal/vertical) was between 1.0 and 1.8, with 75 % between 1.3 and 1.5.

Conclusions

There are apparently considerable differences as to the VDT job market between men and women, as well as differences dependent on education. Some other personal variations such as smoking, exercise, etc, may be secondary to these.

Work postures found among VDT operators stress the need for adjustability in regard to tables, keyboards, displays, and chairs in order to remove restraints on operators in various types of work.

10. Office environment

A number of environmental characteristics are relevant to a discussion of the possible health effects of VDT work. They are defined and briefly discussed in this chapter, mainly as to common parameter values. Their possible health effects are discussed in appropriate chapters in section II.

General physical characteristics include such parameters as temperature, humidity, and floor resistance. Physicochemical characteristics include measurements of air ions, air contaminants, and some other relevant parameters. Illumination characteristics are related to several display characteristics and have been described on pages 31–33.

General physical characteristics

Room temperature and humidity

In an epidemiologic study (91) the room temperature of VDT operators and referents was 23.3 and 24.0 °C, respectively. There was also a slight difference between the room temperatures of the men and the women (23.3 versus 23.5 °C). In another study (17) the temperature of some VDT offices was about 22 °C.

Nylén et al (91) reported the mean relative humidity to be 26.5 % in the work environments of some 400 VDT operators (34.8 % for approximately 150

referents). However, considerable differences were found between the rooms of the men and women (31.7 versus 37.6 %). In the study of Cato Olsen (17) the relative humidity was “consistently” below 30 % (with outdoor weather cold and dry). In another study, two-thirds of the operators complained about dry air (at 30–40 % humidity) (103). The seasonal variation in the air humidity should be kept in mind when these studies are evaluated.

In principle, the relative humidity is related to the body potentials, since body charges are eliminated much faster in humid than in dry conditions.

Floor covering and resistance

Women tend to sit in rooms with wall-to-wall carpeting to a higher degree than men (86 versus 61 %) (91). The floor resistance is generally very high, 9 700 MΩ for men and 8 000 MΩ for women. For neither parameter has any difference been found between VDT operators and referents (doing similar types of work).

Physicochemical characteristics

Measurements of air ion concentrations

In a study (91) of about 400 VDT stations and 150 reference stations “light” air ions were measured

both close to the operator's face and in the workroom at least a few meters from the VDT and the operator (or the referent). For the VDT operators both the positive and negative ion levels were generally significantly increased at both positions in comparison to the corresponding levels for the referents. Exposed levels varied between $0.95 \cdot 10^8$ and $2.62 \cdot 10^8$ ions/m³, while reference values were between $0.68 \cdot 10^8$ and $1.05 \cdot 10^8$ ions/m³. (There was a considerable difference between the men and women — all men $0.55\text{--}1.73 \cdot 10^8$, all women $1.00\text{--}2.40 \cdot 10^8$ ions/m³.)

These data were further separated according to the potential on the VDT screens. It was found that VDTs without screen potential coincided with ion concentrations of some $3 \cdot 10^8$ ions/m³. While workstations with strongly charged VDTs showed ion concentrations more similar to those of the referents for ions close to the face, the levels were still somewhat higher in the room, further away from the VDT unit and the operator. It was tentatively concluded that the VDTs serve as a source of air ions (regardless of electrostatic field), while the electrostatic charges on the VDT screen "trap" negative ions and repel positive ones (91).

Wallach (122) suggested that the electrostatic fields (i) scavenge negative air ions (onto the screen), (ii) repel positive air ions towards the operator's face, and (iii) repel small positive ions from the near air space. These actions would increase the ratio between the positive and negative ions around the operator and also deplete the total ion count. However, the influence of the operator's charge is not clear. These suggestions are in contradiction to the results on measured air ions referred to earlier.

Air particulates

The particles of interest in this discussion are the "accumulation mode particles," ie, particles between some 0.1 and 1 μm in diameter. These particles have normally appeared due to the coagulation of smaller, primary particles.

Cato Olsen (17) examined the total mass of suspended particles in the air of some VDT offices, only particles < 10 μm in size (aerodynamic diameter). The range of 60 measurements was $10\text{--}450 \mu\text{g}/\text{m}^3$. All values above $150 \mu\text{g}/\text{m}^3$ represented periods of cigarette smoking. Nonsmoking areas had a range of $12\text{--}40 \mu\text{g}/\text{m}^3$. These measurements show general agreement with data presented elsewhere (120).

These particles normally carry charges, both due to fundamental statistical reasons (Boltzmann distribution) and to the presence of charging mechanisms. One important such mechanism is interaction between these particles and air ions.

Air contaminants

The sources of aerosol air constituents are diverse. Generally present compounds such as reaction products of sulfur dioxide, hydrocarbon oxidation prod-

ucts, nitrates, etc, are found in many regions, but there is also the possibility of considerable geographic variations due, eg, to proximity to salt water, frequency of inversion phenomena, etc. Other constituents depend on specific anthropogenic sources in the area (metals, metal oxides, many organic compounds, etc). [See the general review presented by the University Park Press (120).]

Furthermore, indoor sources may contribute significantly to indoor aerosol concentrations. One such major constituent is cigarette smoke.

Murray et al (83) sampled some chemical contaminants at 136 workstations in three different sites. The levels of carbon dioxide, carbon monoxide, formic aldehyde, or acetic acid were very low. The major source of carbon monoxide was smoking.

The levels of polychlorinated biphenyls (PCBs) have been measured in VDT workplaces (29). Values of $56\text{--}81 \text{ ng}/\text{m}^3$ were determined, whereas the levels outside the building were only $0.5\text{--}1 \text{ ng}/\text{m}^3$. The authors suggested that capacitor and transformer components of these VDTs may contain polychlorinated biphenyls and that the levels found in these workplaces may have originated from such VDT components. They did not, however, measure the levels in the building in VDT-free rooms. Another study (91) did not reveal any differences in polychlorinated biphenyl concentrations between VDT offices, non-VDT offices, and outdoor levels.

Benoit et al (7) discussed other possible indoor sources of polychlorinated biphenyls (fluorescent lamp ballast and caulking material) and suggested that those emitted from VDTs were the result of previous deposits of ambient polychlorinated biphenyls on the VDT — and subsequently evaporated when the VDT was operated (and thus certain parts heated).

Aerosol deposition

In the absence of any electrostatic field, and in fairly calm office air, diffusion is probably the dominant transport mode of aerosol particles (size < 1 μm). However, in the presence of an electrostatic field, the electric mobility may influence the transport. Particles 0.03 μm in size have a mobility of about $10^{-3} \text{ cm}/\text{s}$ per V/cm (1- μm particles have a mobility of some $10^{-5} \text{ cm}/\text{s}$ per V/cm). Thus, particles in a field of about 10 kV/m will move at about 0.01 mm/s (1- μm particle size) to 1 mm/s (0.03- μm particle size) (17). These transport velocities do however appear small in comparison to ambient air velocities.

The deposition of these particles on a surface (eg, the face) is probably maintained until they are physically removed by washing, etc (17).

The deposition of air particulates has been measured in two VDT offices (17). A substrate was charged with a positive or negative potential and placed at a specific distance from a VDT (with a positive potential). The impacted particles were counted

in an electron microscope. The results are shown in figure 9.

As shown in figure 9, the particle precipitation flux appears to be closely related to the magnitude of the electrostatic field, a result agreeing well with the previous discussion. The relationship between the deposition and either of the electrostatic potentials (on the substrate or on the VDT) is less prominent, but lack of data precludes a definite evaluation on this point. [The data do suggest the necessity of a charge on the substrate (thus on the operator) for excess deposition to occur, but this possibility must be confirmed by further study.]

Description of deposited particles

The particles deposited in the study (17) referred to in the discussion of aerosol deposition were examined as to size distribution and also subjected to some (limited) chemical analysis. The total surface of the particles showed a maximum of around 0.3 to 0.6 μm . Based on these data, it was estimated that a few percent of the aerosol submicron mass in a cubic meter of air will be deposited every hour on the face of the operator. The chemical analysis of larger individual particles disclosed a relative abundance of aluminum, silicon, and calcium followed by sodium, sulfur, chlorine, potassium, and iron, and finally magnesium. The majority of these particles were however probably carbonaceous. In the smaller particles, an enrichment of sulfur and chlorine was found.

Conclusions

A number of parameters, eg, temperature, air humidity, and air velocity are important for comfort.

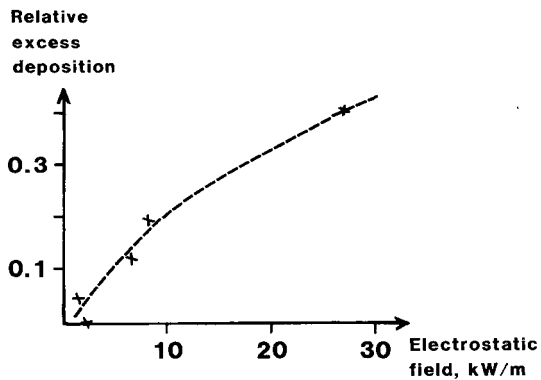


Figure 9. Deposition of aerosol particles (size 0.07–2 μm) on an electrically charged substrate (17). The relative excess deposition has been adjusted for sampling time and ambient aerosol concentration with reference values subtracted (excess flux due to presence of and charge on VDT and charge on substrate shown) — relative values only. The electrostatic field value presented is the calculated absolute value of the field (see pages 25–26 for general comments).

Some parameters, notably air humidity and floor covering and resistance, have also been considered in the etiology of skin rashes and asthenopia (see pages 58 and 49).

Concerning the possible relationships between air contaminants and some observed cases of skin rashes, the conclusion drawn by Cato Olsen (17) was: “It appears, then, that the human exposure to any skin irritants associated with the surface of airborne particles, or existing as a submicron aerosol fraction, will be significantly increased in the presence of electric fields generated by charges accumulated by the human body [p 28].”

11. Job design and psychosocial factors

The psychosocial environment has been shown to have a major influence on many of the reported health effects afflicting VDT workers. It is apparent that VDT operator groups should not only be characterized as to the type of work performed but as to the organizational and social context of the work also. Unfortunately, such evaluations have seldom been attempted in the reviewed field studies.

The structure of psychosocial influences on VDT operators is not well defined. The present communication attempts to present such a structure, largely based on the discussion of Sauter (101) and the report of the NRC Panel (94). [See these papers for further discussion and for other sources, eg, the review paper by Westlander (126), discussing many of these and

alternative concepts.] The reason for including the information in my review is the need to structure the discussion that follows and to pinpoint areas with insufficient information.

In figure 10 three specified regions of the psychosocial environment of VDT work are shown: job requirements, organizational aspects, and social aspects. These regions, singly or in cohorts, introduce a number of objective stressors and present some demand or deficit to the operator. A possible analytical concept is the person-environment fit, which compares the constraints and demands produced by the objective stressors with the need and ability of the operator. Misfit as to one objective stressor will introduce a corresponding subjective stressor.

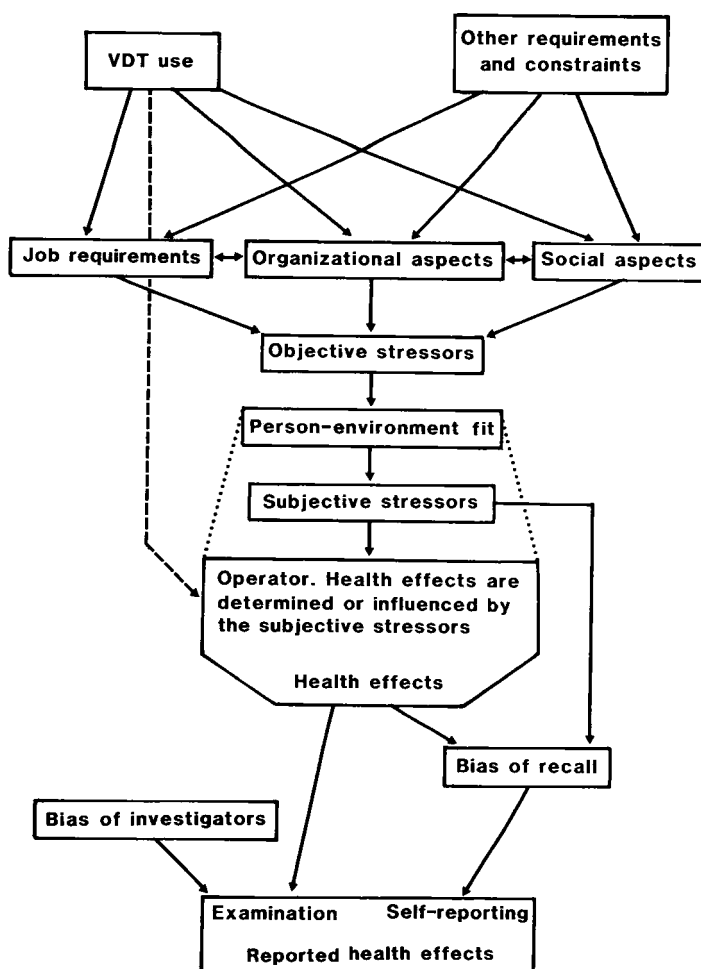


Figure 10. Influence of various psychosocial factors on the reported health effects of VDT workers.

The subjective stressors then determine the stress on the operator, and this interaction can either (i) determine a (subjective) health effect, (ii) influence the development of health effects (with other major causative factors), or (iii) influence the reporting of subjective health effects.

The subjective health effects are reported, either by self-reporting (questionnaires — subject to recall bias) or by clinical or experimental observation (with possible bias on the part of the examiner).

Epidemiologic and experimental results are (at present) largely confined to the impact of different job tasks. Various job tasks also cause a variety of physical stressors (eg, illumination or postural problems) with profound health effects. Further details on this subject can be found in other appropriate chapters.

The other presented concepts are also discussed, but the discussion is rather limited due to the dearth of specific VDT-related information in the literature.

Specific attention should be paid to the interaction between these concepts and the sex of the operator. This attention is motivated both by theoretical considerations and by epidemiologic results (presented

elsewhere in this review). Numerous interrelationships, serving as possible confounders in epidemiologic studies, are apparent between, eg, the sex distribution of operators, job requirements, and the organizational and/or social environment. Unfortunately, several studies have not characterized the operators in these respects, and some which do have not presented any factor analysis on the explanatory power of the individual parameters.

Job requirements

The type of job performed is of major importance for the occurrence of several symptoms (see section II). This phenomenon may be due to some characteristics of the work type which (i) imposes certain physical restraints (and thus the possibility of muscular and/or visual strain), (ii) changes the reporting of subjective symptoms, and (iii) causes direct psychosocial strain.

In those field studies in which the job types of VDT and non-VDT workers have been stated, terminology (and definitions) unfortunately vary. Some examples follow.

Several studies differentiate between data entry and operations with a conversational mode or between data entry and data acquisition modes. A more complete classification of job types has been offered by the NRC Panel (94). It is based on the predominant mode of operation:

1. *Data entry*: Information is keyed into the computer, often according to a set format. Information may be noncontextual. Work pace is often high, with few interruptions, little control of work speed, and few opportunities for decision making. The visual emphasis is on the source document.

2. *Data acquisition*: Data is recalled from the screen, thus with a high visual emphasis on the screen. The input rate is medium, with some interruptions. The control of work speed and decision-making opportunities vary. (Telephone operators are one such example.)

3. *Interactive communication* (conversational mode): This form involves both data entry and data acquisition operations. The input rate is medium and intermittent, with visual emphasis on the screen. Lags for processing occur, and the control of work speed and decision-making opportunities vary. (Travel reservation clerks belong to this category.)

4. *Word processing*: Text entry, recall, searching, format organization, and corrections are involved. The input rate is high but intermittent, visual emphasis shifting between screen and source document. Interruptions are few, with some opportunities for speed control and decision making.

5. *Programming, computer-assisted design and computer-assisted manufacturing*: These jobs are often characterized as professional. The time spent at a VDT unit may vary, but is often fairly low. Input rate is low and intermittent, with visual emphasis on both screen and documents. Interruptions are frequent, and there are major opportunities for work speed control and decision making.

Other definitions and categorizations occur, but in many cases they conform reasonably well with the definitions already presented. [See, eg, the reports of Sauter (101) and Wilkins (127).] Definitions 1 through 4 are commonly referred to as clerical [eg, by Wilkins (127)].

No general statement as to the percentage of workers in each category can be based on the field studies, since they are often workplace specific. In the investigation of Sauter (101), eg, data entry workers comprised 34 % (of workers in some governmental offices), while the percentage was only 10 % in an investigation (18) covering several types of office workplaces — including a large number of telephone

operators and reservation clerks). In the second study (18) the proportion of professional workers was also higher (17 %) than in the first (7 %) (101).

Another field study (102) differentiated between an eyes-fixed mode (data entry or clerical) and an eyes-shifting mode (conversational or professional). The eyes-fixed mode is included in jobs where the VDT may be a major work component, whereas VDT work may constitute a smaller fraction of jobs done with the eyes-shifting mode.

It is possible that the presented definitions may be insufficient for work characterization. Laville (70) found considerable differences as to both position and degree of immobilization between simple data collecting and data ciphering and collecting, although both could be classified as data entry work.

Work type relationships with some aspects of display utilization

Luminance demands on the screen may vary between different job tasks.

In one study (67) the mean luminance on the source documents was considerably higher (163 cd/m²) for data entry work than for conversational work (108 cd/m²). As a corollary, reflections were more prominent for data entry work. Apparently, the data entry operators adjusted their lighting conditions primarily for the source documents, while the conversational terminal operators aimed for good reading conditions on the screen. This finding is of interest for the noted positive correlations between “bothersome visual aspects of VDT as adjusted” with “job attitude of demanding work,” as found by a field survey (102).

Some characterizations of glance times have been made. In the study of Elias et al (31) data entry workers glanced at the screen for durations of about 1 s, and sweeping looks occurred 12–18 times/min. Word-processing operators glanced 6–8 s on the screen and had sweep frequencies of about 8 min⁻¹. Conversational operators glanced for 135 s (one group only).

In simple data collecting (10) 70 % of the time was spent looking at the document, 18 % at the screen, 10 % at the keyboard, and 2 % elsewhere. Glance duration was 3 s for source documents, 1 s for the screen, and 0.4 s for the keyboard. In data ciphering and collecting, 30 % of the time was spent looking at the screen, 28 % at the document, 15 % at the keyboard, and 27 % elsewhere. Glance duration was about 1.5 s for the document, screen, and keyboard.

Organizational aspects

Organizational factors may be associated with VDT work as distress sources. The following specific organizational factors have been suggested: (i) lack of

worker participation in VDT implementation, (ii) inadequate employee training, (iii) job security issues (downgrading, advancement, job loss), (iv) monitoring of employee performance and supervisory style, and (v) presence of incentive pay schemes (104).

In the study of Aronsson (3) workers in higher positions in the organization tended to utilize the VDT as a flexible tool, with considerable user control, while workers in lower positions had their workspace more controlled by the VDT. Lower position workers experienced increasing intensity demand (concentration, endurance, attention) to a higher degree than middle or higher position workers with the introduction of VDTs. No changes were seen in production-related demand (skill or experience as regards the product). Higher intensity demand and routine work have been shown to reduce user control and mental involvement (3, 63).

Social aspects

Several social aspects of VDT work have been studied, eg, interaction between distance to neighbor and social contact or isolation. Some Canadian office worker data (18) showed that distances to co-workers were "about right" for 59 % and "too crowded" for 34 %. (Note that these data refer only to physical distance — and its possible influence on stress.)

Workers in lower positions in the organization experienced the most pronounced decrease in social contact when VDTs were introduced (3).

Social aspects which might produce or affect strain are not limited to the workplace. Attention should be focused also on off-duty situations, for which possibly also some differences in the situations of males and females are relevant. It is plausible that the women's responsibilities, extending into child care and the household, may produce more stress factors than those of men.

Job dissatisfaction, mood disturbance, and general illness were predicted from various social variables (subjects almost exclusively females) (101). Married workers reported less strain, among both VDT and non-VDT users.

It should be noted that many workers using VDTs have a positive attitude towards their work and their use of VDTs. The percentage with such positive attitudes may however differ, depending on a number of factors. One factor is time spent at VDTs (which is confounded by type of job performed). In one field survey (10), of those working with VDTs < 8 h/week, 62 % were positive towards their work. The percentage reporting a positive attitude decreased to 52 % among those working > 8 h/week, and to 28 % among those working > 20 h/week with VDTs. However, another study, cited by Dainoff (24), reported higher job satisfaction with increasing time spent at VDTs.

Job dissatisfaction was 70 % among data entry workers, compared to 28 % among workers using the interactive communication mode in one study (31).

Objective and subjective stressors

The stressor concept and the person-environment fit have been briefly presented in the introduction to this chapter. Unfortunately, great variations in possible stressors are found in the literature, and few explicit results indicate the relative importance of each. It should also be pointed out that there are alternative models for analyzing stress, which have been used in examinations of office work [see, eg, the review by Westlander (126)].

The NRC Panel (94) suggested some stressors on the basis of theoretical considerations and some circumstantial evidence only. They include worker control, participation in job decisions, predictability and controllability of the work, work complexity, role ambiguity, threat of unemployment, quantitative work load, overload due to deadline and occurred delays, worker responsibility, role conflicts, and social support. [Comments on the person-environment fit in relation to these stressors are found in the NRC Panel report also (94).] Many of these stressors were also found in some of the other reports reviewed (20, 24, 104, 105).

Two subjective stressors mentioned in the literature are boredom and fear of health risks (24, 104, 113).

In one field study (58) of two groups of bank clerks (one utilizing VDTs), differences were found as to variety ("this work is varied" versus "with this work one always has to do the same thing"), less variety being found among VDT users. There were small differences as to quantitative and qualitative overload (both less for VDT operators) and no differences for task feedback or cooperation.

In another field study (102) VDT users reported an intermittent work pace with lulls more than did referents. Increasing the VDT work duration (h/week) was associated with decreased job autonomy, but also with a decreased backlog of work and less work pressure. Increased VDT work times were related to higher levels of boredom, fatigue, monotony, and work being specified in detail, but also to higher job satisfaction (24).

Workers using the eyes-fixed mode reported greater clarity in work definition, less job autonomy, less backlogged quantities of work, and less work pressure. Workers in the eyes-shifting mode reported a greater quantity of backlogged work and heavier work pressure (102).

Clerical VDT workers have, in some studies, reported an increasing feeling of being dequalified by VDT work (compared to their old work), less meaningful jobs, greater fear of being replaced, faster work pace, and less control than referents or profes-

sional VDT users (24, 105). In different workplaces clerical VDT workers have indicated both more supervisory and less supervisory control, both less and more peer cohesion, and both a lower and higher work pace than the referents (105).

Most of these stressors are found in both VDT and non-VDT work. Their appearances depend on work types and design, organization etc. With similar stressors, VDT work and non-VDT work are expected to give the same results as regards job satisfaction (94, 101).

Stressors determining or contributing to health effects

In general the relations between (psychosocial) stressors and disease are not well understood. Some specific correlations are referred to in section II in connection with discussions on specific health aspects.

Possibility of bias in reporting

In addition to possible interactions with health effects, subjective psychosocial stress may influence the self-reporting of various physical health effects. This possibility is of primary importance to field or epidemiologic studies — especially if questionnaire responses are low. [See the additional comments in the reports of Smith et al (103) and the NRC Panel (94).]

One probable example of biased reporting is the occurrence of clusters of adverse pregnancy outcomes. The publicly discussed possibility that VDTs may cause harm to fetuses has caused the prompt reporting of several clusters of increased miscarriages (or deformed births) among VDT operators, without the concomitant noting of clusters of (“unusually”) low miscarriage rates. A misrepresentation of the statistics would then occur if these reported “high rate” clusters were to be taken as an indication of an increased rate of miscarriage among all VDT operators as a group. (See pages 62—63 for further discussion.)

Duration of work and rest periods

Breaks in the work are necessary and contribute to comfort. These breaks may amount to doing alternative work, stretch breaks, coffee (and lunch) breaks as well as exercise breaks.

The optimal pattern of breaks has not been fully documented, however. It is possible that short, informal breaks may do more to alleviate symptoms of muscle and eye troubles. This assumption is based on the findings of Coe et al (20). These findings were,

however, criticized by Dainoff (24) on the grounds that a decreasing incidence of blurred vision may be more related to formal (longer) breaks. The suggestions of informal (short) breaks for alleviating muscle complaints are in accordance with the discussions of immobility as a causative factor for muscle pain.

Field survey data on the frequency of eye, muscle, and stress problem composites with varying hours per day of VDT work have been presented (18). For all three (composites of) variables, the frequencies were fairly stable up to 4 h of work per day. Increasing the daily work period to 5 h or more produced an increase in all three problem composites. Similar results were reported by Wallin et al (123). These results were apparently not evaluated as to type of work, which may have differed across the workers with different work durations and which may thus have been a strong confounding factor.

In the US, NIOSH (79) has made the following recommendation for work regimens: “Continuous work with VDTs should be interrupted periodically by rest breaks or other work activities that do not produce visual or muscular fatigue. As a minimum, a break should be taken after 2 hours of continuous VDT work and breaks should be more frequent as visual, mental, and muscular loads increase [p 9].”

Conclusions

Results on subjective psychosocial stressors (job attitudes, etc) show considerable variation, even within single field studies on multiple sites. If such parameters are evaluated in terms of VDT versus non-VDT work (even with job tasks specified), many results appear to be in conflict. Job attitudes associated with VDT work are probably more characteristic of the job rather than (primarily) the VDT factor. Such job characteristics are determined by a combination of job requirement, organizational, and social aspect factors.

VDT work is apparently very diverse in these respects. Several studies suggest that some VDT workers may be described as “privileged” groups (including, eg, professional workers), with more flexibility, more interesting jobs, more autonomy, but probably often with more work pressure. In contrast, some VDT workers may be described as “routine” groups, with more monotonous jobs, less job autonomy, etc.

Unfortunately, practical and methodological problems limit the conclusions that can be drawn based on current literature. Some of these problems are (i) confusion as to terminology and definitions, (ii) the absence of stress factors in many field or epidemiologic studies, and (iii) the absence of factor analysis in some studies that do include stress factors.

Medical and epidemiologic aspects of work with video display terminals

12. General comments on performed epidemiologic studies and field surveys

A number of studies have been performed, investigating the possible associations between VDT work and several health effects. Those studies included in this review are shown in table 13. (For the results, see the appropriate chapters in this section.)

The NRC Panel's criticism of performed surveys

A review of some of the studies has been presented by the NRC Panel (94), together with both general and specific criticism of the surveys. The following methodological problems are discussed: adequacy of theory, adequacy of research design, adequacy of measurements, and adequacy of sampling. The NRC Panel did not find any field study that fully met all these criteria.

Adequacy of theory

In many studies, the lack of a theory linking specific health effects to specific casual factors in VDT work makes study design difficult and chance findings ("nonsense correlations") difficult to explain.

Adequacy of research design

Most studies are cross-sectional, so little knowledge is gained on the possibility that effects may have existed prior to VDT work commencement. Confounding by psychological, demographic, and situational factors may occur, but few studies have been designed to detect such factors. Individual differences, as well as specific job descriptions, have seldom been noted.

Adequacy of measurements

Several study questionnaires appear too vague to generate proper health data. The questionnaires should include multiple indicators of a condition and standardized and focused questions.

Adequacy of sampling

Thus far studies have not been sufficiently specific on diverse populations, diverse job environments, and diverse VDT display parameters. Responses have often been too low.

Additional comments

A number of health effects among VDT operators show a relationship to the sex of the operator. Thus the absence of male:female ratios in epidemiologic studies may lead to erroneous conclusions. [For examples, see the report of Murray et al (84) where three sites were studied with varying male:female ratios for the exposed and referents and which showed varied results as to many complaint frequencies.] Age effects were not always investigated.

Furthermore, job types are important factors influencing complaint frequencies. It is apparent that complex relationships exist between job type parameters, psychosocial factors, operator sex, and complaint occurrences.

One such chain of relationships might be job monotony — little control of speed or decision making — job type — physical or psychological strain, where the job type may also be specific for women. If job type or sex is a causative factor of a specific strain, a simple field study questionnaire designed to study relationships between "user control" and "muscular strain" may well find such a correlation, irrespective of the ("real") causative factor. Factor analysis and predictive models may separate the impact of specific factors in such chains, provided data exist on each factor of (possible/plausible) interest. Design and analysis of the data may however be difficult without an adequate theory on the relationships involved.

VDT-related parameters have not been specified in many studies. Few studies have attempted to differentiate between "good" or "bad" VDTs (in accordance to some specific definition of "good" versus "bad"). This shortcoming may be (partly) due to

Table 13. Epidemiologic studies and field surveys included in this review.^a

Name of author and year of publication	Reference group	Factor analysis	Number of sites studied	Response rate on questionnaires	Health effects studied ^b						
					As-thenopia	Eye damage	Head-aches	Stress	Skin rashes	Muscle pain	Adverse pregnancy outcome
Binaschi et al, 1982 (8)	Yes	No	?	?	No	No	Yes	Yes	No	No	No
Bolinder, 1983 (10)	Yes	No	One	76 %	Yes	No	Yes	No	No	Yes	No
Canadian Labour Congress, 1982 (18) ^c	Yes	No	Several	87 %	Yes	Yes	Yes	Yes	No	Yes	No
Coe et al, 1980 (20) ^d	Yes	Yes	Several	?	Yes	No	No	No	No	Yes	No
Dainoff et al, 1981 (25)	No	No	Several	?	Yes	No	No	No	No	No	No
Edström et al, 1984 (30)	Yes	On-going	Several	Ongoing	No	No	No	No	No	No	Yes
Elias et al, 1982 (31)	No ^e	No	One	?	Yes	No	Yes	Yes	No	Yes	No
Frank, 1983 (36)	Yes	No	Several	40 %	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ghingirelli, 1982 (38)	Yes	No	Two	?	Yes	No	Yes	Yes	No	Yes	No
Gunnarsson & Söderberg, 1979 (46)	No	No	Several	?	Yes	No	No	No	No	No	No
Hunting et al, 1981 (58)	Yes	Yes	Several	?	No	No	No	No	No	Yes	No
Johansson & Aronsson, 1984 (63) ^f	Yes	No	One	?	No	No	No	Yes	No	No	No
Kajiwara, 1984 (64) ^g	Yes	No	Several	?	Yes	Yes	Yes	Yes	No	Yes	Yes
Läubli et al, 1981 (67)	Yes	Yes	Several	?	Yes	No	No	No	No	No	No
McDonald et al, 1983 (76)	Yes	No	Several	?	No	No	No	No	No	No	Yes
Mellner & Moberg, 1983 (77)	No	No	Several	85 %	Yes	No	No	No	No	Yes	No
Murray et al, 1981 (84)	Yes	No	Several	36 %	Yes	No	Yes	Yes	Yes	Yes	No
National Association of Office Workers, 1983 (85) ^h	.	.	.	.	No	No	No	No	No	No	Yes
Ong et al, 1981 (93)	Yes	No	Several	?	Yes	No	No	No	No	Yes	No
Sauter, 1983 (101)	Yes	Yes	Several	> 90 %	Yes	No	Yes ⁱ	Yes	No	Yes	No
Smith et al, 1982 (102)	Yes	Yes	One	48 %	Yes	Yes	Yes	No	No	Yes	No
Starr, 1983 (108)	Yes	No	?	?	Yes	No	Yes	No	No	Yes	No
Tjønn, 1980 (117) ^j	.	.	.	.	No	No	No	No	No	Yes	No
Wallin et al, 1983 (123)	Yes	No	Several	?	Yes	No	Yes	Yes	No	Yes	No

^a Note that some studies have appeared in several reports. The reference given is to the most used report for this review. For a full list of authors, titles, etc., see the reference list.

^b A review of the health effects studied can be found on the following pages: asthenopia: pp 45—50, eye damage: pp 52—53, headaches: p 54—55, stress: pp 55—57, skin rashes: pp 57—59, muscle pain pp 59—62, adverse pregnancy outcome: 62—67.

^c Cited by Wilkins (127).

^d Cited by Dainoff (24).

^e Compared different VDT groups.

^f One of two studies.

^g Few details available in the English summary. Information from this study has been used only in chapters 15 and 20.

^h Tabulation of number of clusters with high frequency of adverse pregnancy outcome.

ⁱ Reported by Smith (103).

^j Tabulation of cases of skin rashes in Norway.

the lack of appropriate theories linking specific VDT parameters to noted health effects.

Definitions and descriptions of health effects have been inadequate in many studies. Some studies indicate differences in occurrences of specific symptoms within general syndromes such as eye strain, muscular discomfort, or headaches. (Skin problems

should probably also be specified as to various types.)

Varying definitions make comparison between different studies difficult. Responses also differ depending on the specific phrasing of the questionnaires, eg, on frequency of symptoms (eg, daily versus occasionally).

13. Asthenopia and eye strain symptoms

In this chapter, the occurrence and possible etiology of subjective complaints of (transient) eye-related problems is discussed. Relevant data from medical examinations are also included. Reading performance, oculomotor investigations, and the possibility of pathological (irreversible) eye changes are discussed later.

A comparison of occurrences of eye strain between different studies is somewhat problematic due to the varying definitions used. The NRC Panel (94) has discussed some of these definitions and has recommended the terms “ocular discomfort” and “changes in visual performance” (findings related to “changes in oculomotor functions” are discussed in a separate

chapter). Eye strain can be defined as a syndrome, based on specifications of a number of symptoms. As is presented briefly in the following discussion, the response will be considerably influenced by the specific definition used.

The term asthenopia would refer to "any subjective visual symptoms or distress resulting from the use of one's eyes" according to the NRC Panel (94). The symptoms of asthenopia have been classified as (i) visual (eg, blurring), (ii) ocular (eyes tired, hot, uncomfortable, or painful), (iii) referral (eg, headaches), and (iv) functional (behavioral). Causes and mechanisms for the appearance of these symptoms are not well known, and neither are the relationships between these (subjective) phenomena and objective measures of eye functions (24, 94). (Note that there are also other definitions of asthenopia.)

It is apparent that the term asthenopia, as defined by the NRC Panel, includes a wider spectrum of effects than ocular discomfort or eye strain. *In the present review, the term asthenopia has been restricted to visual and ocular (groups of) symptoms.* Headache problems will be discussed on pages 54–55 and stress problems on pages 55–57. The terms "eye strain," "visual complaints," etc, are used when reference is made to a specific report where the term is explicitly or implicitly defined. In some studies, eye strain (roughly) corresponds to the ocular group of symptoms of asthenopia.

Occurrence of ocular discomfort

VDT operators (as a group) have high incidences of asthenopia. Reported incidences from field studies vary between 40–85 % (at least occasionally) and 10–40 % (daily). They could be classified as both visual and ocular (24, 25, 31, 41, 46, 47, 77). The incidence varied considerably due to a number of factors related both to the work situation and to the study design.

Most studies report higher incidences of asthenopia among VDT workers than among (corresponding) non-VDT workers (10, 18, 23, 36, 38, 67, 84, 93, 98, 104).

In a few studies [eg, that of Coe et al (20) or that of Murray et al (84), in which one of three sites showed no differences] no significant difference was found as to asthenopia. However, when the symptoms were separated into "fatigue-like" and "irritant-like" groups, a significant difference was found for the former (20). The no difference finding for the one site in the study of Murray et al (84) can be explained by confounding from different male:female ratios for the referents and VDT operators. In Starr's investigation (108) asthenopia tended to occur more often among VDT workers than among referents, but the difference was not statistically significant. Sauter (101) found that VDT use per se was not predictive of eye strain, except that it correlated with

other factors that were predictive, eg, display and workroom lighting problems.

It should be noted that traditional office workers also report high incidences of asthenopia (20, 41, 84, 108).

Reviews generally report the same conclusion of a higher asthenopia occurrence among VDT operators (41, 103, 127), with one exception (94). The NRC Panel (94) suggested that the uniqueness of VDT work in producing ocular discomfort has not been proved and that the complaints are similar to those of "a wide variety of occupations."

Different field studies show different occurrences of asthenopia. One obvious cause is the different criteria used with respect to the individual's frequency of occurrence, from daily to occasionally. These occurrences may differ by a factor of 2 to 5 (41, 46, 47, 84).

Some of the complaints may last until the next day (67, 77, 103). Läubli et al (67) found that 40–45 % of VDT workers reported visual impairments at the end of the day versus 18–31 % of non-VDT workers; the corresponding figures were 11–19 % versus 7–14 % for watching television, 11–15 % versus 6–8 % for reading, 13–17 % versus 8–13 % for the time when one is going to sleep, 2–8 % versus 0–2 % for the next morning, and 1–4 % versus 2–3 % for Sundays. (The higher non-VDT values were consistently found for typists.) Visual symptoms (blurring, etc) often disappeared fairly rapidly after work (103).

Occurrence of specific eye strain symptoms

The individual eye strain symptoms noted vary between different field studies, but they can be separated into the following two groups: (i) eye being painful, irritated, burning, red or tingling or having a "gritty feeling," etc, all related to ocular asthenopia symptoms, and (ii) vision being blurred, double or flickering, ie, visual asthenopia symptoms (10, 18, 31, 36, 41, 67, 98, 108, 127). This separation was also explicitly found in one study (67) by factor analysis.

In some studies (31, 67, 84, 127) the ocular symptoms were more frequent than the visual, but this was not always the case (18, 108). As has already been stated, a significant difference between VDT and non-VDT workers was found only for visual asthenopia symptoms in one study (20). In contrast, an excessive occurrence of ocular symptoms among VDT operators, compared to referents, was found in two sites (84), but only in one site were excessive visual symptoms found. Considerable variations in individual symptoms also occurred within each study reviewed.

In a short note (42) a color visual aftereffect (McCollough effect) was described. Operators watching a display with green characters on a dark background afterwards saw a pink discoloration of white

objects. The effect sometimes lasted a day or longer but was not considered permanent or harmful.

Correlations between ocular discomfort and other variables

The relationships between asthenopia and other VDT work characteristics are many. This discussion has been separated into two parts. The first emphasizes confounding factors of field studies, while the second is more concerned with possible functional relationships. (The distinctions between these two are sometimes diffuse.)

Male:female ratios and age

According to Wallin et al (123) women tend to report a higher occurrence of asthenopia than men. The same result was indicated in the investigation of Murray et al (84), but only for VDT workers.

Differences in asthenopia reporting do not appear to be connected with the age of the VDT operators (77). In the study of Rey & Meyer (98) the higher incidence of asthenopia in persons aged 36–65 years, compared to those aged 18–35 years, was not statistically significant.

Work categories

In principle, the type of work can have a clear influence on the appearance of asthenopia. The regimentation of work and work demand are important factors (102, 103, 127). In a Bell Canada investigation, international operators showed more frequent eye strain symptoms (with a few exceptions) than did the local operators. The reviewer (127) suggested that the higher stress on the international operators might be a factor.

Data entry, data acquisition, and conversational mode operators generally tend to report higher incidences (18, 67).

Läubli et al (67) reported that conversational mode VDT workers had the highest occurrences of each investigated symptom, followed by data entry VDT workers and traditional typists, traditional office workers being last. The authors commented that this profound difference between conversational mode VDT workers and traditional office workers was quite remarkable, since both (in the study in question) performed similar work tasks (payment transactions). The higher occurrence in conversational versus data entry was not unexpected, since the former have their visual attention turned more towards the screen.

When the persistence of discomforts was examined however, data entry workers had more persistent occurrences (67). This phenomenon was not discussed further (67).

Duration of work and work breaks

The majority of studies indicated that the occurrence of asthenopia increased with increasing work time at VDTs (18, 20, 38, 77, 84, 98, 123, 127) — usually with a “break point” after about 4 h of work (18, 20, 98, 123, 127). The symptoms investigated included both ocular and visual asthenopia.

In apparent contradiction to these findings, a few studies did not show any correlation between work duration at VDTs and asthenopia (101, 104). It should be noted that Sauter (101), in contrast to most other authors, included factor analysis and prediction models in his study. Thus it is conceivable that the effects seen by many investigators are due more to the type of job performed (and its corollaries) and lighting problems than to the worktime per se. In the investigation of Smith et al (104) headaches, preceded and accompanied by double and blurry vision, were significantly negatively associated with worktime (h/week) at VDTs. The results, however, were not confirmed by a second test group.

The duration of work without breaks has also been investigated. Mellner & Moberg (77) found a significant positive correlation between the duration of work without a break and the frequency of symptom occurrence. Of those working less than 30 min without a break, 47 % complained of “visual fatigue” versus 66 % of those working more than 30 min without a break. Murray et al (84) suggested that a 15-min break after 2 h of work may not be sufficient to alleviate asthenopia symptoms (at least for the type of work performed at the investigated sites).

Subjective evaluation of work

Some studies have investigated the correlation between subjective work evaluation and asthenopia. In a study on Canadian workers eye problems were more prominent for workers who had less control, higher work pressure, and high job dissatisfaction (18). Worry showed a positive correlation with asthenopia in another study (123). An association between job attitudes (work being hard, fast, and with insufficient time to do the job) and symptoms have also been indicated (102), but the results were not retained in the predictive model analysis.

It is possible that the type of job performed, as well as the male:female ratios, may be strong confounders of these results and that they may better explain the differences found.

Possible influence of visual disorders on asthenopia

It has been suggested that preexisting visual disorders may influence the appearance of asthenopia in VDT operators. [See, eg, the report of Campbell & Durdent (16)]. This possibility can be discussed in the following two ways: (i) do visual disorders influence the appearance of asthenopia and (ii) can differences in (preexisting) visual disorder frequencies explain the

differences between VDT operators and referents with respect to the occurrence of asthenopia?

VDT operators who wear glasses report more eye troubles than VDT operators who do not (67, 77, 101, 103). This statement applies mainly to wearers of monofocal glasses (101). It is possible that incorrect glasses and slight noncorrected astigmatism may be related to these findings, and also the increased reading distance to VDTs compared to "normal reading" might be a problem (16, 46).

This tendency (correlation complaints — using glasses) was also seen in reference groups (67).

Several studies cited by Dainoff (24) indicate that the asthenopia symptoms were not in general related to visual acuity defects, since optical correction had not alleviated the problems in the majority of workers seeking clinical help for their eye trouble. Furthermore visual defects (visual acuity, accommodation, binocular vision, etc) were not significantly higher among the VDT workers than the non-VDT workers, although asthenopia was (98). However, for older people a possible correlation was noted between decreased visual acuity and increased visual complaints at VDTs (98). Läubli et al (67) found a positive correlation between low visual acuity and impairments at VDTs, but not between uncorrected eye defects and complaints.

Irritated conjunctiva was seen more often in VDT workers with ocular asthenopia than in referents with the same disorder (67).

It was tentatively concluded by Läubli et al (67) that "work at VDTs may cause impairments in operators both with and without eye defects [p 938]."

Correlation to musculoskeletal symptoms

Hünting et al (58) and Läubli et al (67) found that the same operators who experienced musculoskeletal problems also indicated eye impairments. The authors suggested that this phenomenon may be due to the more exacting conditions of the work, producing a "general fatigue," manifested as both musculoskeletal and visual problems. Such relationships were also found by Mellner & Moberg (77).

However, the results of Smith et al (102) indicate a more specific relationship, where bothersome lighting aspects of the VDT units produce both asthenopia symptoms and a tendency for the operator to compensate for difficult viewing conditions — at the cost of musculoskeletal symptoms. This suggestion merits further investigation.

Probable causes of ocular discomfort

The finding of Sauter (101) that VDT work per se did not produce increased ocular discomfort is of considerable interest. The study does not suggest that VDT use is not associated with ocular discomfort but rather that control of display and workroom lighting

characteristics can alleviate the problems. There is general agreement on this point (94).

Definite casual relationships between specific display characteristics and asthenopia symptoms have not been established however. Suggestions, based on various findings, have been made for correlations with a number of different display and environmental parameters.

It has been suggested that asthenopia complaints are related to workroom lighting (18, 104), glare (18, 104, 106), dry air (18), screen or character brightness (102, 106), readability (102, 106), flicker (102, 106), and reflections (23, 77).

Some indications in the investigation of Smith et al (102) suggest that ocular asthenopia may be primarily associated with workplace lighting characteristics (glare, brightness of main lighting, shadows, etc) and not display characteristics, while some visual asthenopia symptoms may be more related to the display characteristics. Both of these suggestions were confirmed by factor analysis, and the second was also confirmed by a predictor model and by a test on another VDT/non-VDT group.

Time-dependent display characteristics

Läubli et al (67) found that the degree of oscillation of single characters on VDT screens (used for conversational mode work) correlated positively with ocular asthenopia symptoms, but not with visual symptoms. These findings were supported by medical observations (red conjunctiva). In addition high oscillation values correlated with low visual acuity. The rationale presented was that operators with visual acuity problems increase the character brightness and thus increase the oscillation degree (see also the discussion on page 28). The degree of oscillation was associated with jitter and with low character sharpness.

Visible flicker causes an adaptive overload of the eye since the retina is repetitively overexposed in such situations. It has been suggested (67) that non-perceived flicker may also have some adverse effects on the retina, but this possibility has so far not been confirmed.

A positive correlation between degree of annoyance by flicker and the degree of complaints of asthenopia was found by Stammerjohn et al (106), both for professional and for clerical VDT workers.

In an experimental set up (89) asthenopia symptoms were more prominent after 60 min of exposure to a 30-Hz refresh rate than to 60-Hz or stable text. (The experiment used a chopper disk to simulate the oscillation of VDT screen characters.) Changes in measurable visual function parameters were also seen; see page 51.

Structure-related display characteristics

Difficulties with character resolution, distortions, and readability are intimately linked with job task

performance. A discussion of this problem can be found on pages 30—31.

A significant correlation between annoyance caused by low readability and a high occurrence of asthenopia was found by Smith et al (105), but only for professional and not for clerical workers. The results were not tested by factor analysis, and there are considerable problems of interpretation, as readability could be linked to glare, brightness, etc (105).

Luminance-related display characteristics

Brightness of screen characters has been associated with asthenopia (102, 106) but only in professional workers (106). These results were not analyzed for confounding factors.

Workroom lighting

The parameters associated with lighting, and their interrelationships with the display, have been the most consistently suggested as possible causes of asthenopia among VDT operators. Numerous studies have testified to the inadequate lighting conditions found in many VDT workplaces.

Glare is considered a (tentative) major factor in the development of asthenopia during VDT work. This assumption is supported by the findings of some field studies (19, 106). Furthermore glare (and reflections) occur in general statements on the presence of workroom lighting problems in some other field studies (101, 102), in which factor analyses were also performed.

Reflections on the screen are definitely annoying and should be eliminated. Images reflected from the screen are seen at a further distance than the text presented at the screen surface. This phenomenon has been suggested as a possible cause of adaptation problems, which could presumably cause some asthenopia.

A correlation between the occurrence of reflections and the occurrence of asthenopia has been found in some field studies (23, 77) but not in others (67).

High contrast has been associated with an increase in reported visual asthenopia problems. Conversational mode operators were found to have problems with the contrast between the source document and the screen. The symptoms persisted during the evening. However, the findings were only marginally significant (when low and high contrasts were compared). No such differences were found for referents. Data entry operators had higher asthenopia when contrasts between source documents and tables were high (67).

Workroom environment

An association between dry air and the occurrence of asthenopia has been suggested (18). A possible explanation may be the changes in blink rates found in an

experimental setup (98). A reduced blink rate occurred due to (i) duration of a difficult visual task, (ii) a general low illumination level (screen surrounded by darkness), and (iii) the eye being myopic (near-sighted). As discussed by Campbell & Durant (16), a reduced blink rate can cause a drying effect and mild anoxia of the corneal epithelium. The problem is aggravated by low air humidity.

There is scant information available on these phenomena in VDT situations. A higher blink rate was found among VDT users (compared to non-VDT referents) by Mourant et al (18). Nevertheless, the suggestions made are attractive when the differences between normal and myopic operators are being considered.

Conclusions

There is general agreement between most studies that VDT work is related to higher occurrences of asthenopia symptoms. The occurrences of specific symptoms may, however, differ, ocular symptoms (irritation, pain, red eyes, etc) being in general more prevalent than visual symptoms (blurred, flickering, double vision, etc). Differences between individual field studies as to percentages of each symptom or groups of symptoms are considerable, due in part to the definition of symptoms and the phrasing used in questionnaires. After work, symptoms may persist throughout the evening.

There are considerable correlations between asthenopia occurrence and various other operator-VDT variables. Women report asthenopia to a higher degree than men, and more complaints are found in some types of VDT work; data entry, data acquisition, and conversational mode operators report more problems than professional workers. Duration of work is generally found to be related to the frequency of asthenopia, as is probably the length of work periods without breaks.

Operators wearing glasses report more visual problems than others. However, this difference does not suggest that the increased occurrence of asthenopia among VDT operators can be explained by preexisting visual defects, since no difference in this respect has been found between operators and referents.

The specific causes of asthenopia have not been established. Some contenders for a causal relationship are display characteristics (eg, screen and character brightness, flicker, readability) and workroom lighting characteristics (glare, reflections, contrasts). It is possible that ocular symptoms (irritation, etc) may be more linked to workroom lighting, while for visual symptoms (blurring, etc) display characteristics may be more important.

The relationships between the different display and workroom lighting characteristics are, however, very complex. Relationships with job requirements and

other factors are also incompletely understood.

Nevertheless, it is generally agreed that improving display and workroom lighting performance will de-

crease the frequency of asthenopia occurrence, probably in connection with changed job requirements (including workbreak possibilities).

14. Effects of work with video display terminals on measures of eye functions

This chapter considers the changes seen when VDT operators are examined by ophthalmological methods. The emphasis is on visual and oculomotor functions.

Most attention in this respect has been given to the "triadic near reflex," which is composed of accommodation, vergence, and pupil constriction. It should be noted that these three components of the triad are subject to considerable interrelationships, where the state of each mechanism may exert considerable influence on the others.

Accommodation is stimulated by blur. This phenomenon may supply a possible causal factor between VDT and ocular discomfort. Blurred characters may deprive the accommodation system of this stimulus. However, other stimuli drive accommodation in addition to blur. Accommodative spasm or accommodative asthenopia (fixed accommodation at a near or far point, respectively) may also be related to the incidence of VDT ocular discomfort (94).

Eye movements can be divided into the following extraoculomotor functions: saccadic trajectories, dual-mode movements, higher-level eye movements, and gaze and the vestibuloocular reflex. An abnormal blinking rate may possibly be associated with some symptoms of ocular discomfort (redness, burning, heat sensation, headache) (94). (See also page 49.)

In general, relationships between subjective measures of fatigue (included in asthenopia) and physiological functions have not been successfully established. Temporary changes in oculomotor function may be due to (i) true muscular fatigue (as some studies argue), but also to (ii) adaptation of the sensory organs, (iii) habituation of the central nervous system, or (iv) a decline in motivation. [See also the report of the NRC Panel (94).]

Occurrence of decreased accommodation performance

Performed studies

No correlation was found in an epidemiologic study (102) between VDT use (hours/day, years of VDT use or "current VDT use") and accommodation changes.

There are some experimental studies though which suggest transient changes in accommodation during the day when VDTs are used. They attribute these findings to visual fatigue.

In one such study (47) a significant difference in the drift of the near point of accommodation was found between a "normal" work routine and an "intensified" one for two groups of younger VDT operators. For a group of older VDT operators, no such tendency was found. (The authors speculated that this difference in age groups may be due to the lower elasticity of the lens, which requires the morning to recover.) In another study (92) laser optometry measurements on two groups working with CRT equipment indicated some accommodation changes (dark focus movement and accommodation stimulus-response regression slope changes). The changes were statistically significant only for the group with more taxing work.

In a third study using similar techniques (54) both VDT workers and referents were examined. The near point of accommodation did not change during the day, nor did the regression line (stimulus-response). For neither parameter was there any significant difference between VDT and non-VDT workers. It should be noted that the work was described as "not intense." Others have also failed to observe changes in accommodation between VDT and non-VDT workers [see the report of the NRC Panel (94)].

In another type of accommodation study, the time taken for accommodation from the far to the near point (and reverse) was higher in VDT work than in hard copy work (the differences were about 12–13 ms) (81).

Criticism of the accommodation findings

The first two affirmative studies presented have been criticized by the NRC Panel (94), and the results disclaimed, since "various aspects in the design, analysis, and interpretation of data, the results cannot be interpreted with any certainty [p 146]." In essence, the studies were criticized because they used samples of opportunity, included scant information on demographic and work environments, and did not include appropriate reference groups. No informa-

tion on visual status was presented, and the techniques used in some studies were subject to, eg, general fatigue and subject motivation. No information on statistical analysis was presented.

The last study presented on accommodation time (81) was also criticized by the NRC Panel (94) since it used a subjective measuring method and did not present any data on the variability of the results. The imprecise method may invalidate the (formal) statistical significance of the study. Since four of the six subjects were older than 50 years, and showed the same effect, it is arguable that accommodation plays no significant role in this reported phenomenon.

Vergence

Some VDT work requires movements of the gaze between a document and the screen and thus requires vergence activity. Jitter may also lead to vergence work. Both may possibly contribute to ocular discomfort (94).

Few results from VDT workstations have been reported in respect to vergence. Gunnarsson et al (47) found the near point of convergence to be moved outwards 1–4 cm during a day's VDT work. This effect was increased during "intense" as compared to "normal" work routines. (See the preceding criticism with respect to this study.) A high percentage (about 25 %) of VDT operators working at screens with low contrasts were reported to have exophoria occurring occasionally. No operators at screens with high contrast reported exophoria (67).

Hedman (54) found no change in the near point of convergence either for before versus after work or for VDT versus non-VDT workers.

Some experimental results have also appeared. The divergence time was increased after a VDT task period (compared to before the period), and the vergence amplitude was decreased. No change in convergence time was seen (62).

Lateral phoria changed during the workday, both for VDT-exposed and reference groups. There was no significant difference between the groups however. (Both inward and outward movements of the far vergence point were seen.) Vertical phorias were not affected (40).

Pupil constriction

Transient adaptation glare may cause transient changes in pupil size, as indicated by experimental studies. This possibility is of importance in relation to positive and negative contrast. Alternatively viewing a negative contrast screen and positive contrast documents may then cause overexposure of the retina (15). Others have criticized the experimental basis for this suggestion and its implication (16, 94). (See also page 31.)

It has also been suggested that a high flicker rate of 1–6 Hz may cause a sustained pupillary constriction and thus ocular discomfort. Some early experiments show relief after the blocking of pupillary constriction, while another study failed to show any overall relief (94). The relationships between subjective flicker rates of VDTs and pupillary constriction merit further study (94). The refresh rate of VDTs is substantially higher than the flicker rates used in these experiments however.

Decrease in visual acuity

A temporary reduction in visual acuity (temporal myopization) during VDT work has been reported (49). The myopization was from visus 1.1 to 0.8 for green characters, and from 1.1 to 0.9 for yellow characters. Recovery took about 15 min. This study was criticized on several points (94). The tests for visual acuity could have been influenced by, eg, general fatigue or adaptation to VDT display, which may have reduced contrast sensitivity. The reference group did not perform a similar job task. Furthermore, no details on the statistical analysis were presented. The small decreases in visual acuity found (0.14 diopters for yellow, 0.24 diopters for green) are frequently found in many non-VDT situations.

In an experimental setup (89) relationships between the refresh rate, oscillation degree, and various subjective and measurable eye symptoms were investigated. (The experiment used a chopper disk to simulate the oscillation of VDT screen characters.) At refresh rates of 30 and 60 Hz, several significant changes in measurable visual functions were observed: decreased critical flicker fusion, decreased visual acuity (near vision), increased lateral heterophoria (30 Hz), and decreased contrast sensitivity (60 Hz) (exposure time 1 h).

Other studies (23, 40) found no significant differences in the visual acuity of VDT operators before and after work.

Conclusions

Some studies suggest changes in accommodation and vergence phenomena during near work (both in VDT operators and referents). Other studies, however, fail to confirm these findings. No study presented has shown conclusively any change in oculomotor functions which can be attributed specifically to VDT work.

Since the pupil state was not measured, the optimal or suboptimal accommodative state cannot be assessed. Difficulties remain in defining experimental results as to fatigue or boredom or adaptation (94).

Thus present knowledge is evaluated as suggestive regarding some changes occurring during VDT work,

but inconclusive as to whether any of these changes are specific for VDT work and also inconclusive as to

whether such changes should be considered signs of fatigue or not.

15. Pathological changes in the eyes

The possibility of permanent eye damage due to VDT work has been suggested. Considerable debate has been aimed at the question of cataracts, but acquired myopia has also figured in VDT discussions.

Cataracts are the formation of opacities in the eye lenses; they may (if sufficiently dense) lead to impairment and loss of vision. Small opacities occur in most old people's eyes and are one of the most frequent reasons for loss of visual acuity. The causes of these senile cataracts are essentially unknown, but hereditary factors, radiation (eg, solar UV radiation), diet, or poisons all influence the time of appearance of cataracts. Congenital cataracts also occur, but are very rare. Certain disorders can lead to the development of cataracts in younger people, as can also the prolonged intake of some medicines.

The development of cataracts after, eg, ionizing radiation is a prolonged process, with a latency period of months to years.

Cataracts may appear at first in the central (nuclear) or the peripheral (cortical or subcapsular) regions of the lens. Apparently there are fundamental differences between these regions as to the mechanisms of cataract formation. The nuclear cataracts appear due to normal (or accelerated) age-related pigmentation processes possibly resulting from free radical phenomena. Cortical cataracts are probably due to induced changes in protein configuration and aggregation, leading to localized water-insoluble (turbid and opaque) areas (71).

Some confusion appears due to the different definitions of cataract used in various investigations. Some studies [eg, that of Frank (36)] apparently only report cataracts that interfered with vision (but did not explicitly state the decrease in visual acuity considered for diagnosis), whereas other studies [eg, that of Smith et al (102)] considered all opacities (but they also specified subgroups as to visual acuity decrease).

Cataracts among operators of visual display terminals

Reported cases of cataracts

In 1977 two cases of cataracts had been diagnosed in New York by ophthalmologists as incipient radiant energy cataracts. These diagnoses were confirmed by Zaret (131), whose diagnoses read: "Bilateral incipient radiant energy cataracts and early macular retinopathy of the left eye" (case 1) and "immature ra-

diant energy cataract of the right eye and incipient radiant energy cataract of the left eye."

Both of the men (aged 29 and 34 years) with the cataracts worked as copy editors at the *New York Times*, and both had, within the last few years, been introduced to VDT work. For neither of them could a reasonable and established work environmental factor be determined as the cause although the possibility of a preexisting congenital defect was suggested by the *Times* consulting ophthalmologist. This latter suggestion was disputed by Zaret (131).

Since then, Zaret has made similar diagnoses in at least eight other cases (1980), all involving work with CRT equipment. In the majority of the total of 10 cases, the cataracts were described as "capsular opacification at the posterior surface of the lens" (131, 132).

Possibility of an association between cataracts and work with video display terminals

Epidemiologic studies. Two recent epidemiologic studies have been performed at newspaper offices in the US and Canada. In the *Baltimore Sun* study (102) the incidence of cataracts was 27.1 % among VDT users and 33.2 % among non-VDT users. (In both cases the majority had only minimal opacities, with no decrease in visual acuity. Some 1.4–1.5 % of both groups had cataract formation sufficient enough to reduce visual acuity to at least 20/25. These findings were based on ophthalmologic examinations.)

In the Mount Sinai study of 1 047 workers (36) 2 % of the VDT users reported cataracts, while 0.7 % of the non-VDT users had cataracts. There was a clustering of cases in one study location (10 cases, 5 of which had appeared during the last five years prior to the study). However, many of the VDT cataract cases had developed prior to the onset of VDT work. (It should be noted that these data are the result of a questionnaire, ie, self-reporting on previous diagnosis by different ophthalmologists. There was no information on the criteria used for these diagnoses. Results from the ophthalmologic examinations also included in the study have not yet been reported.)

In a survey made by the Canadian Labour Congress (18), the frequency of cataracts was the following: (i) for people under 45 years of age: 1.1 % for VDT operators and 0.9 % for non-VDT workers

versus 1 % expected; (ii) for people over 45 years of age: 3.6 % for VDT operators and 4.6 % for non-VDT workers versus 4 % expected. No details as to means of examination, nor basis for the "expected" values, were given in the reference. The total number of workers was 2 330.

None of these studies can be considered conclusive as to cataract appearance among VDT users versus nonusers. One problem is the fairly short exposure periods of most workers to VDTs [eg, mean 3.8 years in the investigation of Smith et al (102)], so an influence of VDT exposure on cataract formation (if there should be one) may not have been manifested (36, 102).

Other epidemiologic studies (some of them prospective) on the relation between cataracts and VDT work are under way.

Suggested factors related to video display terminals. The only relevant VDT-dependent factor for cataractogenesis is electromagnetic radiation. Four regions of the electromagnetic spectrum are considered cataractogenic: ionizing, actinic UV, IR, and microwave radiation. For all of these regions, the levels now known to produce cataracts are orders of magnitude higher than those emitted from VDTs (71, 96, 129).

[The suggestions and data of Zaret (131) are apparently due to the confusion of pertinent wavelength regions. In UV radiation the $0.1 \mu\text{W}/\text{cm}^2$ cataractogenic dose refers to the actinic region ($> 320 \text{ nm}$), while the $0.1 \mu\text{W}/\text{cm}^2$ VDT exposure levels refer to the near UV region (350–400 nm). (The highest level of actinic UV radiation measured was some $0.001 \mu\text{W}/\text{cm}^2$ — see table 5, page 19.) In the hertzian region, cataractogenic radiation appears to be limited to the microwave region, whereas the high levels of $10 \text{ W}/\text{m}^2$ referred to by Zaret (131) are found in the low radio frequency and the VLF regions (see table 2, page 15).]

It should be pointed out that the cataractogenic level of UV radiation is characterized by the energy delivered, not the effect. This phenomenon appears to be consistent with suggested mechanisms for, at least, nuclear cataract formation (cumulative) (71). (See the following discussion.)

Tentative evaluation. At present there exist neither epidemiologic nor experimental data to support the suggestion (based on a few case reports) that VDT exposure could lead to cataract formation. Two of the three studies cited [that of the *Baltimore Sun* (102) and that of the Canadian Labour Congress (18)] suggest that there is no such association. Evaluation of the Mount Sinai study (36) must await a report on the

ophthalmologic findings. However, none of the hitherto reported epidemiologic studies can be considered fully conclusive in this respect.

Similar cautious conclusions have been drawn by NIOSH (69, 103) and by others (125). A more definite (negative) evaluation of VDTs as cataractogenic was made by the NRC Panel (94).

Myopia development

A Japanese survey of 1 591 VDT operators and 125 referents has suggested that VDT work may lead to nearsightedness (myopia), since the number of people who had to get corrective glasses during a one-year period was higher than normal (64). Thirty-seven percent of the VDT operators reported deteriorating eyesight in comparison to 26 % of the referents. Since the age distribution of the reference group is not known, no evaluation of the claim can be made.

However, another study (36) revealed no significant differences in the number of eyeglass prescription changes of VDT users and nonusers. (No details were given on the type of eye glasses, etc.)

It is possible, as discussed by Wilkins (127), that the visual effort required in work with VDTs is such that the operators also tend to correct minor visual impairments, while similar impairments among persons in similar, non-VDT jobs may be ignored or even go undetected.

Other possible permanent damage investigated

A number of other indicators of permanent eye damage were (routinely) investigated in the questionnaires and the ophthalmologic examinations of some epidemiologic studies, without the detection of any difference between VDT-exposed persons and referents. Thus there are at present no indications that VDT exposure may lead to glaucoma, maculopathy, iris inflammation, etc (36, 104). [See, eg, the report of Smith et al (104) for an example of these ophthalmologic examinations. It should however be noted that few epidemiologic studies have (so far) studied the possibilities of chronic visual disturbances due to VDT work in detail. [See the brief discussion in the report of Smith (105).]

Most specific pathological processes in the eyes are related to the total energy delivered, not the effect. This phenomenon is of interest when the oscillating character of VDT display pixels are considered (see pages 28–30). Effect-related pathological processes are possible in theory, but will most likely require intensities far exceeding those suggested by the top luminance measurements of VDT pixels (page 29). Most effect/energy relationships are due to the limited temporal resolution of the retina (about 20 ms).

16. Headaches and epilepsy

Headaches can be related both to asthenopia and to stress. [The definition of asthenopia used in this report, that of the NRC Panel (94), includes headache as a referral type of symptom.] Due to the uncertain etiology, headaches have been discussed separately in this chapter.

Another physiological effect is also briefly discussed, the possibility of photosensitive epileptic seizures being induced. The literature on this phenomenon in connection with VDTs and CRTs is very limited.

Headaches

Occurrence

The percentage of VDT operators and referents complaining of headaches varies considerably between different studies, conceivably due both to different work situations and to the design of the field study questionnaires. The incidences reported for both groups vary between 11 and 89 % (18, 84, 103, 108, 127).

Some field surveys have found a significant increase in reported headaches among VDT operators in comparison to referents (18, 36, 38, 102), while other studies have failed to do so (10, 84, 103, 108, 123).

Three different worksites were investigated by Murray et al (84). None of the three showed any difference between VDT operators and referents as to reported headaches. However, at one site, the percentage of headaches was considerably higher (both VDT and referents) when compared to the groups of the other sites. Furthermore, at this site only, VDT operators reported significantly more "frequent headaches" than did the referents (37 versus 13 %). [A similar finding was reported by Bolinder (10).]

Different headache symptoms

Frontal headache occurred more among VDT operators than among referents (36). Ghingirelli (38) reported that 27 % of the VDT operators studied complained of frontal headaches "not related to previous medical history."

Smith et al (102) investigated 17 different headache descriptions in relation to a number of VDT work parameters. The results of the factor analysis are shown in table 14.

The presented data were retained by factor analysis and predictive model fit. In a test of the results on a second group (with different job types) only headache associated with work was retained. The remaining 12 headache variants were not associated with VDT work parameters. [See the report of Smith et al (102) for the details.]

Relations between headache and work type or duration

In one study, cited by Smith (103), an increased incidence of headaches was seen (82 versus 47 %) when some specific VDT work groups (data entry, word processing, file maintenance) were compared to matched referents. Data entry workers complained more of headaches than conversational mode workers (31).

VDT operators who worked > 4 h with VDTs had more frontal headaches and headaches at the back of the head than those working < 4 h (18). An increase in headache occurrence with working time at VDTs was also found by Wallin et al (123). However, Smith et al (102) reported that an increase in the number of hours per week at VDTs was negatively correlated with headaches preceded or accompanied by blurry or double vision.

Table 14. Different headache descriptions and their relations with VDT work parameters (102).

Description of headache	Association found ^a
Occurring during tension, worry and/or stress	Years of VDT work, <i>negative</i>
Associated with work	Bothersome visual aspects of VDT, <i>positive</i> Workplace light, <i>positive</i> Job hard, fast, <i>positive</i>
With eye strain symptoms	Bothersome visual aspects (problem workstation), <i>positive</i>
Superficially located	Eye shift mode, <i>positive</i>
With double/blurry vision	Hours of VDT work, <i>negative</i>

^a *Negative* = significant negative association found; *positive* = significant positive association found.

Correlations between headache and other investigated variables

A group of telephone operators reporting more stress than another group also reported more headaches (19).

There was a positive correlation between bothersome visual aspects of VDT work and some headache types (table 14).

Epilepsy

Perceived flicker may have some bearing on the possibility of inducing photosensitive epileptogenic seizures, although the flicker rates needed to induce these seizures are much lower than the refresh rates used [8–14 Hz versus 30 (interlace) to 50–70 Hz (normal) (94)].

Epileptic seizures have been observed in connection with television viewing. The phenomenon appears to be rare however and of concern to a small fraction of the population (1/2 500 to 1/10 000) which could potentially be subject to it. Nevertheless, persons known to be at risk should be medically examined prior to the use of VDT equipment (16, 127).

In the investigation of Nishiyama et al (89) a small percentage (< 2 %) of operators and referents had had an epileptic seizure within the previous five years. There were small differences between the exposed and the referents.

Conclusions

An increased occurrence of headache among VDT operators in comparison to referents is possible, as indicated by some studies, but other studies have failed to verify this suggestion. It is possible that a more precise specification as to type and location of headache in the questionnaires may reveal differences; this possibility has been suggested by the result of one study. (Such differences are probably appropriate for an effect of diverse etiology.)

Differences in headaches as to job tasks can also be suggested, and these differences may partly explain the various results when headache occurrence and duration of VDT work are compared.

The relationships between VDT work and headaches need further study.

The present state of knowledge indicates that epileptogenic seizures induced by VDT flicker are fairly improbable events.

17. Stress and psychological effects

Mention has repeatedly been made of psychosocial problems among VDT operators. Such problems include mood disturbances and (secondary to these) psychosomatic disorders. These effects are less well documented, though, and are only briefly discussed.

Mood disturbances reported in the literature are anger, frustration, irritability, anxiety, confusion, and depression. A classification of “fatigue” into three groups has been proposed in connection with the “F scale” [cited by Binaschi et al (8)]. The second of these groups — “difficulty in concentration, due to mental fatigue,” contains several mood disturbances.

Some physiological disturbances have also been noted, which are presumably linked to these mood disturbances (a psychosomatic etiology). Among these psychosomatic correlates are gastrointestinal disturbances, muscular or “psychic” tension, changes in heart rate, and sweating. Effects on sleep pattern and appetite have also been studied in a few reports. Headaches have been discussed elsewhere (pages 54–55), since they may also be related to eye discomfort.

Measures of stress hormones (adrenaline and noradrenaline) have been reported in one study by Johansson & Aronsson (63).

Occurrence of mood and psychosomatic symptoms

Occurrence of symptoms

Emotional disturbances and their psychosomatic correlates occur frequently in the general population. These high occurrences are also seen among VDT operators.

In the study of Elias et al (31) the occurrences of nervous disturbances (anxiety, irritability, and depression) among VDT operators varied between 25 and 70 %. Psychosomatic disorders (constipation, swellings, palpitations, and chest pains) varied between 15 and 50 %, while 15 to 45 % had an inadequate sleep pattern.

Anxiety and depressive disorders were reported by about 40 % of the VDT operators in another study (38). Irritation was found among 14 % of the VDT operators in the investigation of Johansson & Aronsson (63), and 44 % of the Bell Canada telephone operators who used VDTs reported nervousness or general stress (19).

Differences between operators and referents

A number of studies have investigated the possible differences between VDT operators and referents as

to the occurrences of psychosomatic symptoms. The results have varied.

According to one study (36) irritation and sleep disturbances were correlated with the use of VDTs.

Four other studies (18, 63, 84, 127) found symptoms more frequently among some groups of VDT operators only.

In one study, by Heron (56), VDT clerical workers had higher "stress points" than referents, while VDT-using programmers had the lowest "stress points." In another investigation (18), mood and psychosomatic complaints (irritation, sleepiness, dizziness, and loss of appetite) were higher among VDT operator groups than among similar referents for professional, data entry, and "dialogue" work, but not for "clerical" work. (Note that job classifications may vary.)

Smith et al (103) found that fatigue, nervousness, and "pounding heart" were found more often among VDT operators than referents at one site. A second site showed excess irritability, depression, and anxiety among VDT operators, while no differences between VDT operators and referents were seen at a third. The first worksite was characterized as having "rigid work procedures," while operators at the two other sites held jobs that were more flexible and autonomous, had more user control, etc.

Gastrointestinal disturbances were more common among some VDT groups (intermediate VDT work duration) in comparison to referents (and to VDT operators working more than 50 % of their worktime at VDTs) (63).

In contrast to these findings, two studies found no association between psychosomatic symptoms and VDT work. In one (8) "fatigue" (defined according to the "F-scale" mentioned earlier — including nervousness, anxiety, etc) was not significantly higher among VDT operators than among referents. In the other (101) a negative correlation was seen between VDT work per se and mood disturbances. No significant correlation was found between VDT work per se and illness symptoms. (It should be noted that these results were based on factor analysis, and the results only reflect VDT use, not VDT work parameters.)

Physiological measures of stress

In one study (63) several physiological measures of "stress" were reported for VDT operators and referents. The adrenaline levels of VDT operators were higher before noon than the referents', while the opposite was true in the afternoons. These variations correlated with self-reported changes in anxiety, fatigue, and stress. The average workday adrenaline levels were also higher among VDT operators than among referents, and the differences remained also in the evenings after work. (All individual levels were reported in percentage of corresponding levels on days off from work.)

Relations between stress and work factors

Psychosocial stressors

As can be inferred from the preceding discussion, job types and job stressors are probably of major importance to the determination of mood symptoms. Sauter (101) found job future uncertainty to be positively correlated with mood disturbances, illness symptoms, and job dissatisfaction. Job control or social support was not associated with mood or illness symptoms, but was negatively associated with job dissatisfaction. Work load demands were positively associated with illness symptoms, but not with job satisfaction or mood symptoms.

Telephone operators placing international calls were somewhat more susceptible to "strain," ostensibly due to "cross-cultural" differences while placing calls (19). Lower control of work, higher job pressure, lower job satisfaction, higher degree of monitoring, or "incorrect" distances to other workers were associated with higher "stress" (19). (This report did not however perform any factor analysis.)

Duration of work

Longer duration of work has been linked to higher stress according to Wilkins (127). However, no association (by factor analysis) has been found between hours of daily VDT use and mood or illness symptoms (101). Johansson & Aronsson (63) concluded that operators with intermediate jobs apparently have a greater incidence of gastrointestinal symptoms.

Breaks in work routine

A number of complaints about unscheduled breaks in processing have appeared. In the investigation of Wallin et al (123) 81 % of the questioned VDT operators experienced "disturbances" due to long and varying waiting times. In another study (63) 63 % of the respondents would have liked to maximize the waiting time to 5 s, while only 5 % could accept waiting times of more than 30 s.

Johansson & Aronsson (63) reported that 60 % of VDT operators working > 50 % of their worktime at VDTs could "not relax" during unscheduled breaks, compared to about 10 % of those working only occasionally at VDTs.

During one unscheduled break (duration 3.5 h), the levels of adrenaline and diastolic blood pressure were significantly higher than during normal VDT work. Irritation and stress were also increased during this break period (63). (The study was performed once with six individuals.)

Physical parameters of work

Professional VDT operators had a positive correlation between level of complaints of several physical

VDT parameters and their level of complaints about mood disturbances (106). The study did not use factor analysis, so the interrelationships of this finding with, eg, eye discomfort were not evaluated. Of possible interest, however, are the increased complaints of "noise from VDTs" (see page 27).

There has been conjecture regarding possible health effects from exposure to positive and negative ions, especially on mood parameters (122). So far, these have not been substantiated for VDT operators.

A comprehensive literature review (4) concludes: "There is no evidence that concentrations of small air ions between 10^6 – 10^{10} ions/m³ constitute a health hazard to man. The effects of ion concentrations $>10^{10}$ ions/m³ on man are more difficult to evaluate since long-term studies of the biological effects of small air ions are lacking [p 110]." In the report of Nylén et al (91) levels of air ions around VDT units were generally below $5 \cdot 10^8$ ions/m³.

Conclusions

Mood disturbances (anxiety, irritability, etc) and psychosomatic disorders (gastrointestinal problems, etc) appear to be more linked with job design and psychosocial stressors in the job than with the use of VDTs per se. In contrast to many other health findings, no definite increase has been found in complaint levels with increasing VDT worktime.

Neither is there a clear correlation between job designations (data entry, professional, etc) and mood complaints. Further site-specific variables are warranted, such as autonomy, social contact, job uncertainty, etc. (Note that these variables may differ within a specific job type.)

One specific VDT-related factor has however been suggested, ie, unscheduled breaks and long waiting times for processing are a cause of complaints among VDT operators (similar phenomena do not occur among referents). In one investigation, these complaint levels have been supplemented by data on adrenaline levels.

18. Skin rashes

Considerable attention has been given to the possibility that work with VDTs may involve a risk of developing facial skin problems. So far, a number of case reports have appeared describing facial rashes among VDT operators in Norway (with isolated reports from Great Britain and Sweden).⁶

These cases include 4 in Great Britain (1978) (100), 35 in Norway (various locations, 1979–1980) (117) [Some Bergen cases were described in detail in published reports (72, 88).] and 1 in Sweden (Umeå, 1982) (39). Additional facial rash cases among VDT operators do apparently appear (as indicated by case reports), but these have (so far) not been verified.

Occurrence

Description of observed facial rashes

The Norwegian rash episodes usually started after a few hours of exposure and began with itching, followed by erythema and sometimes also papules. These phenomena were usually confined to the cheeks. The redness developed successively and was

usually graded as weak (72, 88, 117). In a few cases, a diffuse redness appeared on the cheeks and other portions of the face (88). Minor desquamation was frequent (117). These cases could be characterized as neither allergic contact dermatitis, photosensitive dermatitis, nor rosacea (88).

The British cases also showed erythema and papules, but the investigators found some resemblance to rosacea (100). The reported Swedish case was "similar to the Norwegian and British cases." Some desquamation was found (39).

The rashes usually subsided within the day or over the weekend (39, 72, 88, 117).

Epidemiologic studies

The number of cases is small compared to the large number of VDT operators. The appearance of skin rashes was observed only in some locations and appears to be unknown in most offices. An earlier epidemiologic study (36) failed to find any differences between VDT users and nonusers (in newspaper offices in the US and Canada) as to the occurrence of skin rashes. However, Murray et al (84) found an increased occurrence of self-reported skin rashes, itching skin, or allergic skin reactions at all three of

⁶ Published reports are limited to a description of some of the Norwegian cases.

the sites they investigated. The differences in occurrences between VDT and non-VDT workers were significant for only one of the three sites however (62 versus 38 %).

Possible causes

Relation to work

Considerable efforts have been made to find other causes for these outbreaks than VDT work, but (so far) without success. No atopic dermatitis in childhood (or among relatives) was found in the Norwegian cases (117).

The rash victims consistently claimed to have developed rash only when working with VDTs and that the rashes disappeared away from VDT work (39, 72, 88, 100, 117). In at least one case, a relation between the time spent working with the VDT and the intensity of the rash was suggested (39).

The four British cases worked full (three cases) or part (one case) time at VDTs. Another VDT operator also worked full-time with the same VDT make (in another office of the same factory) without developing any rash. Several other operators also worked with VDTs for short periods in the same office as the rash cases without developing any lesions (100).

Provocation tests have been carried out with varying results. Five patients were placed in front of a VDT for three work periods without any rash developing (88). Another investigation claims however to have provoked facial rashes in two operators (72).

Other possible factors

One consistent observation in many reports has been the coincidence of the facial rash with dry periods (low relative humidity) and with the frequent occurrence of electrostatic phenomena.

Humidity was generally low, around 40 % (100) or below (72, 117), "usually between 20 and 30 %" (72). Floor carpets were often of a type prone to electrostatic charging (72, 88, 100, 117).

One investigation (72) has reported the successful provocation of skin rashes among four rash-prone VDT operators with the aid of a van de Graaff generator (producing a strong electrostatic field).

The possibility of radiation-induced skin lesions has been dismissed. Some investigations of ionizing and nonionizing (UV) radiation levels were made on the actual VDTs, and the levels were found to be very low to nondetectable (88, 100) (in accordance with the levels reported on pages 19–20).

Suggested mechanisms

The localization of the problem to only a few offices has led to the suggestion of other (complementary?) factors being involved in the development of these facial rashes. In this context, the presence of electro-

static fields between the VDT and the operator, and the possible redistribution and thus enhanced operator exposure to ambient aerosols has been investigated (17). These investigations were performed at Televerket, Bergen, Norway, where the six cases referred to by Nilsen (88) worked. (The general findings of this investigation are described on pages 25–26 and 37–39). The specific details pertinent to this discussion follow.

High electrostatic fields were found around some of the "rash-prone" VDTs, but also around other VDTs for which no rash episodes had been reported. High electrostatic body potentials were found almost exclusively in offices where rash episodes had occurred, but they were (indiscriminately) found on rash-prone operators, nonrash-prone operators, and also on the investigators (17).

In an experimental study (17) the deposition of excess aerosol material increased with increasing electrostatic fields between the VDT and the operator (in comparison to referents) (17) (see figure 9). The author suggested that electrostatic fields (especially influenced by the electrostatic charge on the operator — and augmented by the electrostatic charge of the VDT) enhanced particle deposition on the face, and, depending on the presence of aerosol contaminants and on susceptible individuals, skin reactions to these contaminants might occur.

According to this suggestion, the air humidity would be important, since the electrostatic charge on the operator is strongly dependent on air humidity. All the cases of skin rashes in Norway occurred during the winter (Tjønne HH, personal communication), when the humidity is low. Murray et al (84) found no obvious relationship between air humidity and the occurrence of skin rashes. The authors pointed out however that the measured humidity may not be representative of either seasonal or year-round conditions.

Attempt to prevent facial rashes among rash-prone operators

Increasing the air humidity (to about 50 %) has reduced rash reactions "markedly." The elimination of carpets prone to static electricity in combination with high humidity resulted in the disappearance of the facial rashes (72).

The placement of a grounded metal screen or a water screen (glass container with an electrolyte solution) between the VDT and the operator has in some cases reduced the skin rashes (72), but this procedure has not always been effective (39).

The placement of a window glass between the VDT and the operator has had varying effects in that it has both reduced and intensified the rash reactions (72, 100).

One operator reduced his reactions by viewing the VDT at an oblique angle (100).

Conclusions

So far, no causal relationship has been established between VDT exposure and the occurrence of facial rashes. The majority of VDT workers appears not to be at an increased risk of such disorders.

However, the reported few and geographically localized cases of facial rashes among VDT operators have not been adequately explained. The possibility of VDT work involvement in combination with other factors remains. (The strongest argument for a VDT work involvement is the absence of any viable alternative explanation.) Such factors include electrostatic

phenomena, low humidity, and probably individual variations (sensitivity, habits, etc) among operators.

Further studies of these effects appear warranted. The electrostatic phenomena should be better characterized. There are indications that the electrostatic charge on the operator may be more relevant to a discussion of these phenomena than the electrostatic field from the VDT.

Present knowledge does not support the possibility of electric fields causing facial rashes of this type "by themselves" (17). Unfortunately, the possibility of an influence of varied ambient pollutants on the skin rashes has not been adequately examined.

19. Muscular discomfort

Several studies have indicated the occurrence of various musculoskeletal symptoms among VDT operators. The incidences vary with a number of other variables, due both to the operators' situation and to the study design.

The musculoskeletal pain may be of various types (pain, stiffness, fatigue or tiredness, cramps, numbness, tremor, etc), occur at various locations in the body (neck, shoulder, arms, etc), and occur with varying frequency for each operator (daily, occasionally, or seldom/never).

Most studies are based on subjective reports of muscular discomfort in field studies. These questionnaires were, in some studies, supplemented by medical observations of, eg, painful pressure points and/or posture measurements.

Some but not all field studies used reference groups. Job task classifications were made in some studies. Confounding factors (notably male:female ratios) have been checked for only in a few studies.

In this chapter, the reported incidences of musculoskeletal complaints from field studies are presented and discussed. One major issue is whether the reported complaints are unique to VDT work or common with other types of office work. Some possible explanations of the occurrences of musculoskeletal symptoms are also given. Further data on posture measurements are found on pages 34—37 and on different job types on pages 39—43.

Occurrence of musculoskeletal symptoms

When the musculoskeletal complaints of VDT operators have been compared with those of (appropriate) referents, the results have varied. Some studies testify to higher occurrences of musculoskeletal problems

among VDT operators, eg, that of Frank (36), while others have failed to find any higher occurrences (10, 18, 40). Murray et al (84) found an increase in musculoskeletal complaints in one of three worksites examined. (See the discussion on sex distribution that follows.) In the investigation of Smith et al (102) VDT users were found to suffer greater musculoskeletal discomfort than non-VDT users, but this result did not survive analysis by confounding factors.

In two of the three workplaces examined by Murray et al (84), subjects were asked both whether a specific symptom "has occurred" and whether the symptom "occurred frequently or constantly." For both VDT and non-VDT users, the latter responses were between 10 and 50 % of the former. A more detailed analysis (made by myself) shows that, in these two sites (each comprising some 100—150 subjects), there was a clear tendency for VDT operators to state that their reported symptoms were "frequent or constant" to a higher degree than the referents.

At one site, 22 % of the operators reporting symptoms stated that they were "frequent or constant," versus 13 % of the referents. The percentages were averaged over 14 different question responses concerned with musculoskeletal problems.

At the other site, the percentages were 49 % (VDT operators) versus 34 % (referents). This finding (greater "frequent or constant symptoms" among VDT operators) was true for 12 of 14 questions at site 1 [not "shoulder soreness" (16 versus 34 %) nor "loss of strength in arms or hands" (11 versus 17 %)] and in all 14 questions at site 2. [The proportion of men was 62 % (site 1) and 20 % (site 2) among the VDT operators and 37 % (site 1) and 25 % (site 2) among the referents.]

Similar observations were made by Bolinder (10), who found that VDT operators tended to report their problems as more serious than those of referents.

Musculoskeletal symptoms in various body locations

More definite differences between different types of jobs (including both VDT and non-VDT jobs) were seen when specific complaint locations were examined.

In one study (58) data entry workers (VDT) and typists (non-VDT) had more complaints in the neck and shoulder regions than conversational mode workers (VDT) or traditional office workers (non-VDT). These subjective symptoms were verified by medical examination and were also manifested as painfully limited head mobility.

Data entry workers (VDT), conversational mode workers (VDT), and typists (non-VDT) complained more than traditional office workers (non-VDT) of back pain (58). Data entry workers (VDT) had more arm complaints than had conversational mode workers (VDT) and typists (non-VDT), who in turn had more complaints than traditional office workers (non-VDT). Pain during isometric contractions of the forearm increased in the following order: traditional office workers — conversational mode workers — typist — data entry workers (58).

Upper leg problems were reported primarily by data entry workers (VDT), followed by traditional office workers (non-VDT) (58).

A higher incidence of primarily neck and shoulder complaints among some types of VDT jobs compared to (some) non-VDT jobs has also been seen in a number of other studies (18, 36, 43, 108).

Correlations between musculoskeletal symptoms and other variables

Sex

The sex of the operator appears to have a strong influence on the reporting of musculoskeletal problems. In the investigation of Murray et al (84) the average symptoms reported (14 questions) were ap-

parently related to the sex of the VDT operator. For the referents no such relation was seen (table 15).

Wallin et al (123) reported a number of possible confounders, related to work periods, job types, organization, etc, to be different for the men and women of their study. Unfortunately, few studies have been conducted in which both sex (male:female ratios) and various job characteristics have been analyzed by factor analysis.

Work categories

As has already been indicated, the type of job has a strong influence on the reported musculoskeletal complaints. In general, data entry workers often have a higher incidence of pain in specific body locations, as compared both to non-VDT workers (18, 58) and to other VDT workers (18, 31, 58, 77).

Other types of work result in a more varied response between VDT and non-VDT workers. Clerical VDT workers reported more complaints than their non-VDT counterparts, while professional VDT or telephone VDT operators did not (18).

In one Canadian study, a considerable difference in back muscle pain was found between international and local telephone operators (both groups using VDTs). The reported incidences were 48 versus 24 % (19).

Duration of work

A higher incidence of neck, shoulder, or back complaints has been found with increasing time spent at the VDT (18, 40, 77, 123, 127). The incidence of pain in the arms, hands, or legs was found by Wallin et al (123) to be associated with increasing time spent at the VDT but not by Smith et al (102).

The increase in reported pain was found to be a fairly monotonous function of the workhours, both in field studies (19, 123) and in experimental studies (40). Such increases with worktime were, however, seen in both VDT and non-VDT work (40).

The incidence of reported pain was significantly and positively correlated with the length of the work periods (in the range 30 min — 2 h) (77). Relief was noted during the lunch break (40).

Subjective evaluation of work

Pain and stiffness in the extremities were not significantly associated with job-attitude variables, while pain and stiffness in axial musculature were, especially with "job being hard, fast, with little time to do it" (102). (These findings were however not verified by a predictive model.)

Another study (which did not include factor analysis) indicated a higher incidence of reported pain when (i) the job was controlled by the system, not the user, (ii) job pressure was high, and (iii) job satisfaction was low (18).

Table 15. Relationship between male : female ratios and the reporting of musculoskeletal symptoms (84).^a

Percentage of women in group	Percentage of workers reporting symptoms	
	VDT operators	Referents
21	24	.
38	30	.
63	.	26
75	.	42
80	62	.
81	.	22

^a These data are subject to a number of other confounders; see the text for a discussion of this problem.

Relation to display, illumination and eye strain

Pain and stiffness in the shoulders, neck, and back appear to be correlated also with visual aspects of VDT work — such as bothersome lighting, glare, and flicker. These findings were supported by a model predictive analysis, but not by the study of a second group of VDT and non-VDT workers (in the same study) (102).

In another field study (77) a positive correlation was noted between the occurrence of eye strain and musculoskeletal complaints.

Bifocal glasses

In the discussion, presbyopes who lean their head back in order to use the lower part of their bifocal glasses have been suggested to be at greater risk of developing muscle pain. So far this has not been confirmed by any study. (In some of the studies made, the number of wearers of bifocal glasses was too small for analysis.)

Smith et al (102) found that wearers of bi- or multifocal glasses had lower incidences of pain and aches in the axial musculature. This association was not, however, verified by subsequent analysis of the data.

Some notes on the etiology of observed musculoskeletal complaints

In general, the musculoskeletal problems noted are considered to be caused by postural restraints due to the workstation and the type of job performed. The various elements of the workstation to be viewed impose demands for viewing distances, etc, which are (presumably) met at the cost of postural problems.

The problems are principally due to incorrect posture (wrong ulnar deviation of the hands, excessive bending of the neck, changes in the lumbar region during sitting — due both to chair characteristics and leg room — wrong elbow angle, etc), to static work (eg, due to the absence of wrist or back support), and to immobilization (58, 77, 94).

Immobilization and static work lead to the obstruction of blood vessels, with a painful accumulation of waste products (70, 94).

In one field study (58), correlations were seen between (i) hand and arm pain and keyboard height (above some 7–8 cm), (ii) pain and excessive ulnar abduction ($> 20^\circ$), (iii) absence of (used/usable) support for the arms and pain in the neck, shoulder, and arms, and (iv) increased head inclination and turning with pain in the neck and shoulders. These findings correlate well with the general remarks already made and with the developed standards. A decrease in table height was associated with increased shoulder, neck, and arm pain, but this occurrence was attributed to the absence of document holders, not to the table height per se.

The importance of workstation design (as indicated)

has been confirmed by others. In another field study (84) excessive keyboard height (from floor or chair) and excessive viewing angle were suggested to be associated with the occurrence of musculoskeletal problems. [Due to the strong confounding influence of varying male:female ratios, no analysis was possible.]

Similar confirmation has also been presented by Sauter (101), who found chair comfort and workstation configuration to be predictors of musculoskeletal pain. In specific, musculoskeletal strain increased with increasing viewing angle and was alleviated by the presence of a detached keyboard. (These results were not subjected to factor analysis.)

However, these results should not be used to define workstation design with a “correct posture,” for several reasons. Differences as to the correct posture exist in the literature [eg, on elbow angle (94)]. Individual dimensions vary considerably from the norm — especially if male and female or ethnic differences are considered. Individual preferences may show considerable variation, as does work demand.

An adjustable workstation is of major importance. One example has been given by Sauter (101), in which the absence of a detachable keyboard was found to be associated with increased muscular pain occurrence. Murray et al (84) suggested that flexibility is needed for seat height, backrest height and tension, keyboard height, and screen height and tension.

The need to move is stressed by several physiological functions (skin discomfort at the point of contact with the chair, the requirement of the extra peripheral pump for muscle contraction, etc).

Immobilization is related to type of work (both VDT and non-VDT). In two variants of data entry work, simple data collection and data ciphering and collection, the former was associated with a higher degree of immobilization (70). (See further page 36.) In general, data entry work probably results in more movement restraints than, eg, conversational mode work (31).

Permanent damage

There are no studies on possible chronic muscle disorders. Available literature on non-VDT situations suggests however that wrist and/or lower back disorders may develop. These suggestions are complicated by the somewhat different postural constraints and strains in VDT jobs compared to non-VDT jobs (94, 103).

Conclusions

The occurrence of musculoskeletal problems per se does not appear to be specific to VDT operator groups; many problems can be found in other types of traditional office work (eg, typing) also. However, some data suggest that the frequency of occurrences (for an individual — reported as often compared to

seldom) may be higher among VDT operators. This latter point needs further study however.

There are apparent differences also as to the site of pain. VDT workers have a tendency to report more centrally located pain (shoulders, neck, possibly upper arms), while in non-VDT workers (especially typists) pain is felt more in the extremities. These findings are probably explainable by the different constraints in posture imposed by the different workstation configuration of, eg, data entry (VDT) workers and traditional typists.

The occurrence of musculoskeletal pain in VDT operators is also correlated with sex (more often in females than in males), type of work (data entry highest), duration of work, etc.

The causes of muscle pain in VDT operators are to be found in the constraint of posture and immobilization in specific types of VDT work and workstation design. Correct and adjustable workstation configuration, in connection with flexibility of posture, variations in job tasks, and short breaks, are obvious methods of alleviating these problems.

20. Adverse pregnancy outcome

The appearance of several clusters of pregnant VDT operators, for which an unusually high miscarriage or birth defect rate was reported, has been given considerable attention. Debates on the possible influence of VDT work on pregnancy outcome have led to apprehension and worry among VDT operators, and a need to investigate this possibility.

Table 16. Reported increased incidence of spontaneous abortion (SA) or congenital defects (CD) among VDT operators (US and Canada) (28, 85, 113 and an unpublished memorandum by Binkin et al). Only clusters occurring (at least partly) in the time period 1979–1980 are included.^a (ND = neonatal death, PB = premature birth).

Place of occurrence	Date	Events noted ^b
Sears Roebuck, Dallas, Texas (Dept 168)	May 1979— June 1980	SA = 7/12 (ND = 1/12)
Defense Logistic Agency, Atlanta, Georgia	October 1979— October 1980	SA = 7/15 CD = 3/15
Toronto, Star, Toronto, Ontario	May 1979— May 1980	CD = 4/7
Canadian Air Line, Dorval, Quebec	February 1979— February 1980	SA = 7/13
Old City Hall, Toronto, Ontario	1980—1981	SA = 10/19
Surrey Memorial Hospital, British Columbia	May 1978— October 1982	SA = 3/7 CD = 2/7 (PB = 1/7)
Office of the Solicitor General, Ottawa, Quebec	1979—1982	SA = 4/7 (PB = 1/7)

^a Additional clusters have since appeared in, eg, Renton, Washington (3 adverse of 5), Alma, Michigan (17 adverse of 32), Atlanta, Georgia (6 adverse pregnancies of 15), Great Neck, New York (6 adverse, total number of pregnancies in the period not stated), San Francisco, California (19 adverse of 48), and Gander, Newfoundland (3 adverse of 31) (85, 113, 136, 138).

^b Number of occurrences/number of pregnancies in a (specified) group (only abnormally high incidences noted).

A number of employers, in both North America and Europe, accept worry about dangers of VDT work as a justifiable reason for the woman to be assigned to work away from VDTs during (the remainder of) a pregnancy. These agreements do not imply an implicit acceptance of VDTs as dangerous during pregnancy; the explicit motivation is the woman's worry.

The basis for this concern is examined in some detail, first as to the clusters of adverse pregnancy outcome that have appeared and epidemiologic studies that have been performed and second as to the possible factors in VDT work that may conceivably cause a teratogenic effect. An evaluation, based on available data, is made.

Reported clusters of spontaneous abortions or congenital defects

A number of "clusters" of high frequencies of spontaneous abortion or birth defects has been reported, primarily among VDT operators in the US and Canada. Those found in the literature, and which occurred during 1979 or 1980, are shown in table 16. Only the first three clusters have been reported in detail, and only the first two have been subjected to a statistical analysis. Additional clusters have since appeared, a comment in *Microwave News* in May 1984 cited 11 clusters being "made public" since 1980 (79, 136). Further cluster appearances have been claimed by, eg, the 9 to 5 Campaign (85). A few clusters have also been reported from other countries.

Statistical evaluation of reported clusters of spontaneous abortion

The six reported groups with high rates of spontaneous abortion within the time period summer

1979–summer 1980 can be summarized as follows: number of pregnant women in each group 7–19 (mean 12.2), percentage of spontaneous abortion in each group 43–58 % (mean 52 %). There was no trend in the percentage values as the group size increased.

A plausible explanation for these recorded clusters is the combination of chance (random accumulation of a number of spontaneous abortion cases in a few of the many groups of pregnant women working with VDTs) together with the selective identification of only these groups.

A realistic model based on these data and suggestions is presented in appendix 2. It appears that the expected number of groups with high (more than 50 %) spontaneous abortion rates is in agreement with or in excess of the number of observed (reported) groups. The calculations in appendix 2 thus support a chance explanation of these findings.

The same explanation for these clusters has been suggested by Binkin and co-workers in an unpublished memorandum in 1981. The memorandum states that “Over a three-year period twenty-five hundred groups would have excess adverse outcomes at $p = 0.05$, 500 at the 0.01 level, and 50 at the 0.001 level on chance alone.” (The group sizes and assumed total number of pregnant women were somewhat different than what is used in appendix 2.)

Statistical evaluation of reported clusters of congenital defects

The three reported clusters of congenital defects can be summarized as follows: number of pregnant women in each group 7–15 (mean 9.7), percentage of congenital defects in each group 20–57 % (mean 35 %).

An analysis similar to that for the spontaneous abortion cases is also made in appendix 2. The expected number of groups with birth defect rates similar to those observed exceeded the number of observed groups. This evaluation does not differentiate between different congenital defect disorders. In the *Toronto Star* cases (four congenital defects) there were four different defects, ie, underdeveloped eye, club foot, cleft palate, and hole in the heart. (One mother reported a family history of cleft palate.) These differences do not support the possibility of one single external factor as a cause of (all) these effects (32).

When some of the groups that were reported later (Renton, Washington, and Gander, Newfoundland) are included, a trend is noted whereby the maximum percentage for reported birth defects decreases with increased group size, eg, rate 57 %/group size 7, rate 29 %/group size 7, rate 20 %/group size 5 and 15, rate 10 %/group size 31. Such a trend, while not statistically tested, is in accordance with a chance explanation of these findings. (See table 2 in appendix 2.)

Epidemiologic studies

So far, only a few epidemiologic studies have been performed on the possibility of a correlation between VDT work and adverse pregnancy outcome. In one (36) the data were insufficient to be used in evaluating the possibility of birth defects or miscarriages.

The preliminary results of a second study, by McDonald et al (61, 76), is presented in detail in the following discussion. This detailed scrutiny is motivated by the use of the presented data by a reviewer (28) to claim a significant correlation between VDT use and miscarriages. The authors of the study (and myself) disclaim such a correlation.

A case-referent study in Finland was based on existing registers of congenital defects (Kurppa K, personal communication). There was no difference in VDT exposure between mothers of malformed and normal children. (The relative risk point of, eg, mothers working with VDTs for > 4 h compared to those not working with VDTs was 1.0.) The study comprised 2 950 women.

A Japanese study (64) on 1 591 VDT workers included 50 pregnancies. Thirteen were described as “abnormal pregnancies or abnormal deliveries.” Of these 13 pregnancies, 4 (8 %) ended in abortion, while 6 others (12 %) were described as “threatened abortion.” These abortion rates appear to be similar to abortion rates reported for other worker groups in Japan. The small size of this study makes it impossible to draw any conclusions however.

A study is at present being conducted in Sweden jointly by the National Board of Occupational Safety and Health and the National Board of Health and Welfare to investigate the relations between work at VDTs and adverse pregnancy outcome (30). This study utilized existing registers to define a study group of 500 mothers with adverse pregnancy outcome, each with two referents. In the second phase, these mothers were asked to complete a questionnaire on their work history, including use of VDTs. The steering group⁷ has made an evaluation of the preliminary results of the study and have found no indications that VDT work leads to increased risks of spontaneous abortion, congenital defects, or perinatal death. The final results are expected in February of 1985.

NIOSH is initiating a study on the possible effects of VDT use on reproductive health (79). The study will, if possible, include a prospective component. Other studies are being planned, eg, in Denmark and the US (Michigan and North Carolina).

⁷ The steering group is composed of experts and representatives of trade unions and employers' organizations.

The Montreal study

Aim and methods

The project's aim is to find correlations between a number of job-related factors and certain adverse pregnancy outcomes, ie, spontaneous abortion, congenital defects, and low birth weight (61).

All women attending 11 Montreal hospitals for childbirth or after a spontaneous abortion during a two-year period are being interviewed. The interviews concern the present and past pregnancies, socioeconomic data, data on the job situation during each pregnancy, etc (61).

The results now presented (76) have been derived from the interviews made the first year (May 1982 to May 1983) and are only concerned with the first pregnancies of women who entered the hospital because of a second pregnancy. Thus the pregnancy for which they entered the hospital was not the pregnancy from which data were derived for the analysis.

Presented results

(All significance tests mentioned were performed by me.)

A total of 14 708 women were interviewed in detail — 18.1 % had had a spontaneous abortion, 4.5 % of the rest gave birth to defective children, and 7.6 % gave birth to children with a birth weight of less than 2.5 kg.

The spontaneous abortion rates were significantly higher for women with employment (in general), and specifically for certain job categories. Some work-related factors were correlated with higher rates of spontaneous abortion (range 20.7—28.6 %). Among these factors, VDT work was related to a rate of spontaneous abortion of 21.5 %. *Compared with all women in the study*, this higher rate was statistically significant ($p < 0.05$).

There were small differences in the rates of congenital defects in the study. The authors made no detailed analysis of these data, since the types of deformity were too heterogeneous. Work with VDTs did not show any significant increase in (the total) birth defect rate compared with that of the total cohort.

Low birth weight was more prevalent for women without employment than for those employed. Work with VDTs was not correlated to any increase in the rate of low birth weight.

Table 17. Rate of spontaneous abortion among women in the Montreal study (76).

Time of first conception	Rate of spontaneous abortion	
	VDT workers (%)	Non-VDT workers (%)
Prior to 1981	10.4 ^a	11.6
During 1981	63.5	69.7

^a 6.1 % for women using VDTs for 1—4 h/week, 12.3 % for women using VDT for more than 20 h/week.

The only significant increase noted for VDT workers in this study was that of the spontaneous abortion rate.

Evaluation of the data

The authors of the study expressed doubt about the validity of the VDT data with the following statement "This shorter interval for first conceptions ending in an abortion (to the present pregnancy), in conjunction with the trend to a wider use of VDT's systematically biases the relation between the two events. . . [pp 5—6]" (61). They also presented some data on VDT and spontaneous abortion by separating 1981 first conceptions from prior to 1981 first conceptions (see table 17). The apparent dubious spontaneous abortion percentage data for 1981 conceptions are explained by the selection bias previously referred to and by the conclusions of McDonald et al (76), which can be summarized as follows: Few women who started their first pregnancy in 1981 and gave birth to a living child will have their second pregnancy completed during May 1982 to May 1983 (prerequisite for inclusion in the study). In contrast, a large proportion of the 1981 conception women whose pregnancy ended in a spontaneous abortion will start a second pregnancy fairly soon, and thus they will become eligible for inclusion in the study.

These phenomena are studied in some detail in appendix 3. In principle, the outcome of the first pregnancy will influence the probability of and the time interval to the next pregnancy, and this occurrence will in turn influence the fractions of women with different pregnancy outcome which are included in the study. If a subgroup, such as VDT workers, is increasing rapidly during the pertinent time period, then the relative proportion of spontaneous abortions and other outcomes will also be disturbed — thus any comparison between such a group (VDT workers) and other groups includes a systematic error. In a quantitative model of the McDonald study (see appendix 3), the impact of this error for VDT workers and spontaneous abortion was estimated. It appears that *the increase in spontaneous abortion among VDT workers noted in the report of McDonald et al (76) is fully explainable by this error (selective bias)*.

In light of this selection bias, the difference noted between women using VDTs for 1—4 h/week and those using VDTs for > 20 h/week is difficult to evaluate, since no data are available on the possible time trends of VDT use (h/week, person).

Possible factors related to the use of video display terminals and adverse pregnancy outcomes

In attempts to explain the aforementioned clusters, some VDT-related factors have been discussed as possible causes. Factors under discussion have been

electromagnetic radiation and fields, emission of polychlorinated biphenyls, and stress.

Electromagnetic radiation and fields from VDTs are not found at harmful intensities, as evidenced from a large number of measurements in many frequency bands (see pages 15—17). Two specific bands are discussed in this presentation, ionizing radiation (X rays) and low radio frequency magnetic fields.

Polychlorinated biphenyl emission from VDTs has been suggested in one report (29). This suggestion has been repudiated by other investigations. VDTs are not considered a source of such emission (see page 38).

Stress has been suggested as a cause of the presented miscarriages. As discussed on pages 55—57, stress appears to be more linked to the type of job and the work situation than to the use of VDTs per se. It should be noted that a link between stress and spontaneous abortion has yet to be verified (Binkin et al, unpublished memorandum).

X-ray emissions in relation to observed adverse health events

There is a general consensus that VDTs do not emit ionizing radiation (X rays) at detectable levels (see pages 17—18).

DeMatteo (28) has cited a few results of the BRH (14) as an indication of possible excess emission from some VDTs. However, these results did not appear during normal operating conditions, but during extreme test situations not compatible with normal operation. The makes were recalled or denied access to the (US) market (and have never appeared on the Canadian market).

Furthermore, even on the extreme assumption that such a unit should have been used under such extreme conditions at any of the cluster sites, the exposure levels would not exceed the background levels (about 2.5 mSv/year) and would be considerably below existing standards for the general population.

In addition, of the eight cases in the Sears cluster (including one neonatal death), only two worked full-time (160 h/month) with VDTs, the remaining six worked only about 6 h/month at the VDTs. The VDT units were not of the same makes as the faulty ones tested by the BRH (14 & Binkin et al, unpublished memorandum).

The VDTs used by the *Toronto Star* cluster were tested as to ionizing radiation, and no radiation was detected. Nonionizing levels were very low or nonexistent, well below existing standards (32). The same results were found for the VDTs used at the Old City Hall in Toronto, where another cluster appeared. The “faulty” units tested by the BRH (14) were not used in Canada.

It can be concluded that ionizing radiation from VDTs cannot be considered a viable explanation for the reported clusters of adverse pregnancy outcome.

The effects of magnetic fields of very low frequency on chick embryogenesis

Description of studies performed

In a series of experiments, Delgado and his co-workers (26, 27, 118, 119) have indicated the possibility that low intensity, VLF magnetic fields may adversely affect developmental processes.

A number of newly fertilized hen eggs (probably White Leghorn) were exposed to pulsed magnetic fields (duration about 0.5 ms) with frequencies of 10, 100, or 1 000 Hz, intensities of 0.12, 1.2 or 12 μ T. After 48 h the embryos were examined as to gross morphology of the intact embryo and histology of sections of the embryo.

In the first report (27) 36 of 42 exposed eggs (versus 4 of 26 controls) showed gross morphological abnormalities.⁸ In the exposed eggs, the cephalic nervous system appeared to be more susceptible to abnormalities, compared to the truncal nervous system, the heart, vessels, or somites.⁹ Although effects were seen in the exposed eggs at all frequencies and all amplitudes, they were more pronounced (both statistically as to number of eggs involved and qualitatively as indicated by histological sections) at 1.2 μ T (compared to other amplitudes), and at 100 Hz (compared to the other frequencies). Both 100 and 1 000 Hz showed malformations in at least some organs in all exposed eggs (100 versus 15 % in controls), but the morphological abnormalities were more pronounced in the 100 Hz series (especially at 1.2 μ T). No statistical evaluation was reported.

In a subsequent report (119) a larger number of experiments were described, and there was also some variation in pulse form. The repetition frequency was 100 Hz, and the pulse duration 500 μ s in all the experiments. A significant increase in morphological abnormalities among the exposed versus the control eggs was found only for certain pulse types, and at amplitudes of 0.4 or 1.0 μ T. Other pulse types at these or other amplitudes showed no difference between the exposed and control eggs (see table 18).

Time derivative of the magnetic field

It has been suggested by others [eg, by the SSI (110) and Tell (114)] that the relevant parameter for biological effects of the aforementioned magnetic fields would be the time derivative of the amplitude **B**; **dB/dt**. I have therefore reexamined the data from Ubeda et al (119) as to **dB/dt** based on reported rise times of the pulses. The results — and their associa-

⁸ Normal embryos were those which had reached at least stage 9 [see the report of Hamburger & Hamilton (50)] after 48 h, and also exhibited normal morphological and histological appearance.

⁹ Somites refer to segmented blocks of epithelioid cells adjacent to the neural tube of embryos, later developing into bone, connective tissue, dermis, muscle, etc.

Table 18. Rate of change of magnetic fields and effects on chick embryogenesis (pulse repetition rate 100 Hz).

Pulse type ^a	Rise time (μ s)	Magnetic field amplitude B (μ T)	dB/dt (mT/s)	Abnormalities ^b		Abnormality ratio ^c
				Exposed eggs	Control eggs	
A	100	0.4	4	9/30	12/37	0.92 NS
		1.0	10	23/55	13/55	1.77 NS
		10.4	104	14/41	12/41	1.16 NS
		13.9	139	17/32	11/32	1.54 NS
		104	1 040	17/59	13/53	1.17 NS
B	2	0.4	200	20/24	8/23	2.40 p < 0.005
C	42 (6.9) ^d	1.0	24 (145) ^d	11/30	7/29	1.51 NS
D	42 (2.0) ^d	1.0	24 (500) ^d	17/24	2/12	4.26 p < 0.01

^a See the report of Ubeda et al (119) for the details, and the text for further discussion.

^b Abnormal eggs/total number.

^c % exposed; % control, NS = not significant (p > 0.05) [p values from the report of Ubeda et al (119)].

^d Revised data according to an unpublished memorandum by Hansson-Mild in parentheses. (See the comments in the text.)

tion with the experimental results — are shown in table 18.

As can be seen from table 18, there is no apparent relationship between the dB/dt and the abnormality ratios. Significant results were seen for 24 and 200 mT/s, but nonsignificant results were also seen at these and other rates.

Thus it appears that the descriptive parameters repetition frequency and the magnetic field amplitude B or its time derivative dB/dt are insufficient to differentiate between “potent” and “nonpotent” magnetic field conditions in these experiments. One further possibility would be the pulse shapes, possibly characterized by their Fourier transforms (spectral analysis). Preliminary investigations by the SSI indicate that the pulse shape C and D would extend up to some kilohertz, while pulse shape B may possibly extend up towards the megahertz range (Paulsson L-E, personal communication).

The rise times of the C and D pulses reported by Ubeda et al (119) are apparently in error due to uncertain technical procedures (unpublished memorandum, Hansson-Mild K). New rise times have been given, and they are included in table 18. While these new data do change somewhat the correlation between the dB/dt and the effects, they do not materially affect the preceding conclusion — that dB/dt does not appear to be a major factor determining the effect.

These results have so far only been published by Delgado and his co-workers. Results verifying some of these findings have been claimed by Hansson-Mild. Another group (led by Miller) has, however, apparently failed to verify Delgado's results (137). Both the results of Hansson-Mild and Miller will be published fairly soon. It should be noted that some differences existed between Hansson-Mild's and Miller's parameters. The exact parameters to be used for these experiments have yet to be defined. Extensions of the results of Delgado to other animal species (mice) are planned by the SSI.

Possible relationship of these results to exposure to video display terminals

It has been suggested that, if these results of Delgado's are accurate, then one possible extension would be the possibility of embryogenetic effects of magnetic fields from VDTs (114 & Hansson-Mild K, unpublished memorandum).

The arguments as presented are:

1. Delgado's results (if accurate) indicate the existence of frequency windows (resonance frequencies) for embryological effects of VLF magnetic fields.
2. One relevant parameter should be dB/dt. The dB/dt values presented are of the same order of magnitude as that of the horizontal deflection system (1–43 mT/s at a distance of 0.3 m (see page 24).
3. Thus the possibility of effects of VDT exposure on embryos should be investigated. (Such experiments are under way or planned in both Sweden and Canada.)

My own evaluation and opinion are as follows:

1. The results of Delgado et al are interesting but should be repeated by independent groups. At present there are too many uncertainties in the study design for one to consider them reliable. Work on this problem is in progress (Hansson-Mild K, unpublished memorandum).
2. The results at present contain several diffuse points, especially on the relevant exposure parameters to be used. Delgado claims (27) the existence of a frequency window at 100 Hz. In the data (27) however all the eggs exposed to both 100 and 1 000 Hz showed some abnormalities, although those at 100 Hz showed the “most consistent and powerful inhibitory effect on embryogenesis.” The issue of the rele-

vant frequencies is not resolved, especially in light of the various pulse shapes and the presented Fourier analysis discussion. Furthermore, the possibility of an "amplitude window" (as claimed by Delgado) should preferably be supported with a suggestive explanation of a mechanism explaining such an effect. Very few eggs were used in some combinations of amplitude and frequency when the frequency and amplitude windows were defined.

3. At present, the experimental conditions do not show agreement with the magnetic fields of the VDTs. First, the frequency issue is not resolved (and the claimed frequency of maximum effect, 100 Hz, is far from the discussed relevant VDT frequency of 15–30 kHz). Second, although the dB/dt ratios correlate (although possibly not at relevant frequencies), the correlation between dB/dt and the noted effects remains to be shown.

In conclusion, I am of the opinion that, while the results of Delgado et al are interesting, their relevance to VDT situations has not been shown, based on presently available data.

Conclusions

A number of "clusters" of high frequencies of spontaneous abortion or birth defects has been reported among VDT operators in (primarily) the US and Canada. A small number of such clusters (about 5–10) is reported every year.

The frequency with which clusters of adverse pregnancy outcomes appear are consistent with the assumption that female pregnant VDT operators as a group experience normal occurrences of miscarriage or birth defects. The clusters that do appear should thus only represent those few groups with outcomes at the extreme high end of the probability distribution of adverse pregnancy outcomes.

The data available on epidemiologic studies do not suggest an increased frequency of adverse pregnancy outcome among VDT operators.

The possibility that these clusters may be explained by chance is further strengthened by the observation that it is the only explanation which is consistent with known data on exposure to VDTs and with relevant scientific knowledge on teratogenesis in general.

Alternative possible explanations based on electromagnetic radiation or fields from VDTs cannot be supported by presently known data. No measurable levels of ionizing radiation are found at VDTs, and the levels of nonionizing radiation are considerably below present occupational standards.

Chick embryogenesis has been adversely affected by pulsed magnetic fields in studies reported by one group. So far, the magnetic fields used in this study have not been shown to be similar to those from VDTs, neither as to the frequency nor to the amplitude. Several research groups are actively investigating these phenomena.

The conclusion that VDT units do not cause miscarriage or congenital defects is based on the following rationale: One plausible explanation of the observed clusters has been given (that of chance alone), and no alternative explanation has been found, based on known data.

Video display terminals and health

A technical and medical appraisal of the state of the art

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Video display terminals (VDTs) have come into increasing use in most countries. In newspaper offices in the United States (US) and Canada, for example, the number of VDTs increased from 155 in 1971 to 30 000 in 1981, a figure which corresponds to a 70 % annual increase. The annual growth of VDT users in Canada is supposedly 20–35 % per year at present. By the year 2000, forecasts suggest that 60 % of the North American workforce will be using VDTs.

In the wake of this expanding use of VDTs, reports and expressed concern about adverse health effects among VDT operators have appeared. This concern has been largely directed towards ergonomic aspects (effects on vision) in Europe and the possibility of radiation hazards in North America. In later years, our knowledge on these possible effects has been expanded and also, in part, consolidated; therefore some consensus statements are feasible.

The information and evaluations in this document are divided into two sections, a technical-occupational hygiene description of factors (VDT or non-VDT originating) which may conceivably be of interest in respect to the health effects of VDTs and a medically and phenomenologically oriented description of reported/suggested/alleged health effects, when possible discussed with reference to the technical part.

There are fundamental objections to the use of terms like “prove” or “impossible” in empirical science. Accordingly, the presented summary on VDT and health must be considered to be limited by available knowledge.

The evaluations included in the summary are based on the following principles:

1. A *consensus statement* is made if (i) there are several independent studies confirming the statement and (ii) there is no scientifically based opposition to the statement (or, if there is, it has been judged to be irrelevant or inconsequential to the issue by the reviewers).

2. A *statement* is made if (i) there are a few independent studies confirming the statement and there is no

scientifically based opposition to the statement (or, if there is, it has been judged irrelevant or inconsequential to the issue) or (ii) there are several independent studies confirming the statement, but there are also some contraindicative studies.

3. A *comment* is made if the information is considered relevant to the issue but does not qualify as either a consensus statement or a statement.

Technical and occupational hygiene aspects of video display terminals

The cathode ray tube

The VDTs considered in this document are based on the cathode ray tube (CRT) technique for presenting written information. CRT devices contain the following elements of interest: (i) a cathode, serving as the electron source; (ii) a grid, used to modulate the intensity of the electron beam; (iii) anodes, which accelerate and focus the electron beam; (iv) deflecting devices, regulating the impact area on the screen, normally through an arrangement of magnetic coils outside of the tube; (v) a screen, consisting of two layers, a metal layer given a high potential for accelerating the electrons and a fluorescent screen material, phosphor, where the electron energy is converted to light; and (vi) a conductive glass envelope.

The generation of text or a picture on the screen is dependent on three cyclic procedures: (i) a vertically deflecting magnetic field with a frequency (refresh rate) of between approximately 50 and 80 Hz, (ii) a horizontally deflecting magnetic field with a frequency of between (normally) 15 and 25 kHz, and (iii) modulation of the electron beam intensity in order to produce light or dark spots along the horizontal sweep, with frequencies in the megahertz region.

The electron beam passes across one picture element (dot) in a very short time, on the order of 100 ns, and returns about 15–20 ms later.

Electromagnetic and electrostatic radiation and fields

A VDT based on the CRT technique is a potential source of several distinct electromagnetic spectral bands. X-ray radiation arises within the CRT tube when the fast electrons are quickly slowed down by the screen material. Optical radiations are purposely derived by the phosphor material in the screen, when interacting with the electrons. High radio frequency radiations appear, apparently related to the frequency of the intensity modulations of the incident electron beam towards the screen. Low radio frequency radiations emanate from the horizontal deflection system. Very low frequencies arise around the refresh rate and apparently depend on both the vertical deflection system and modulations of the electrostatic field by the intermittent negative electron beam.

Electrostatic fields frequently appear in relation to the acceleration potential of the CRT.

The electromagnetic spectrum of radiation from VDTs has been reasonably well investigated. Levels of radiation have been found to be small compared to present occupational and environmental standards. No standards, however, have been defined for very low frequencies or for electrostatic fields.

Consensus statement. VDTs are not a source of harmful intensities of electromagnetic radiation in the X-ray, ultraviolet, visible, infrared, microwave, or high radio frequency parts of the spectrum.

Considerable electrostatic fields from several types of VDTs have been detected.

Statement. Low radio frequency radiation (< 3 MHz) and very low frequencies (< 3 kHz) are not considered to be harmful at intensities emitted from VDTs. This assumption is based on occupational standards, on comparison with other (ubiquitous) emitting devices, and on theoretical considerations.

Comment. Adverse health effects of moderate intensities in the very low frequency band (frequencies around 50–100 Hz) have been suggested, but have as yet not been substantiated. Neither have specific correlations with frequencies and intensity levels emitted from VDTs been established.

The measured electrostatic fields from some VDTs may possibly be of relevance for the appearance of skin rashes among VDT operators, but this possibility has as yet neither been confirmed nor repudiated.

Sound and noise

Sound emissions from VDTs have been detected, both in the audible and in the ultrasound regions.

Consensus statement. No consensus statement is appropriate.

Statement. The limited number of measurements on the levels of sound emissions suggest that they will not cause any harmful physical effects.

Display characteristics and readability of the text

The information received by the operator is derived from that of the screen. This information transfer is subject to the legibility of the screen characters. A number of parameters are relevant for a discussion of health effects. These parameters have been divided into three groups related to the luminance, the structure, and the time variation of the information presented.

The luminance and the structure profoundly affect the readability of the text. (This document does not, however, include evaluations pertaining to readability unless they are pertinent to discussions of health effects and discomfort, notably asthenopia.) (Asthenopia is defined in this document in accordance with the recommendations made in 1983 by the US National Research Council's Panel on Impact of Video Viewing on Vision of Workers (the NRC Panel) as "any subjective visual symptoms or distress resulting from the use of one's eyes.")

Consensus statement. Display parameters as they are found in many workplaces, and in combination with workroom illumination, are important factors in the development of asthenopia. In a number of field surveys, several of these parameters have often been found not to conform to recommendations. This finding was particularly notable for contrasts, illumination levels, glare, and reflections.

Statement. Oscillation characters of the screen display are probably of some importance in determining discomfort and asthenopia. Some notable parameters are flicker, jitter, and oscillation degree.

One specific issue is polarity (positive, ie, dark letters on bright background versus negative, ie, bright letters on dark background). Positive polarity appears to be related to improved performance (higher reading speed and fewer errors), to suitable workroom illumination settings, and possibly also to less discomfort caused by the operator's gaze moving between the source document and the screen.

Comment. Unfortunately, some of the oscillation parameters appear not to be well documented. Literature values of decay times (roughly the duration of the luminance of a bright "dot") vary by several orders of magnitude. These differences may be due to measuring difficulties — decay times in the microsecond region have been reported.

The refresh rate must be considerably higher than 50 Hz (up to 70–80 Hz) in order to avoid flicker in positive polarity VDTs.

The operator and workstation design

A number of characteristics of the operator have been shown to influence the incidences of reported health effects of VDT operators. Parameters discussed include sex, age, body dimensions (as influencing posture at a VDT workstation), educational status, etc.

A second area of major importance is the design of the workstation, its impact on viewing distances and angles, and work posture. Some principles of workstation design are briefly discussed.

Consensus statement. Viewing distances to the screen are generally longer than to the document or to the keyboard, but the range of observed viewing distances is fairly large.

No ideal work posture can be specified. Individual adjustments and measures to prevent immobilization are of prime importance.

Statement. The sex of the operator is a major factor in the variations found in occurrences of some observed health effects.

The type of job performed at the VDT is a cofactor closely linked to the sex ratio; female operators often have the more monotonous jobs. Education is another aspect of the same set of interdependent factors (sex, education, work type).

Age may be another factor for some health effects.

Office environment

Several workroom characteristics are discussed in connection with some health effects, such as asthenopia and skin rashes. General physical parameters are, eg, temperature, humidity, and floor resistance. Some physicochemical parameters are air ion concentrations and air contaminants.

Consensus statement. No consensus statement is appropriate.

Statement. In the presence of a (strong) electrostatic field between the VDT and the operator, aerosol particle deposition on the operator's face is increased.

The air humidity is an important factor for determining the electrostatic charge on the operator.

Comment. Aerosol particle deposition and air humidity may possibly be linked to cases of skin rashes among VDT operators.

Job design and psychosocial factors

The psychosocial environment has been shown to have a major influence on many of the reported health effects afflicting VDT workers. It is apparent that VDT operator groups must also be characterized

as to the type of work performed, as well as to the organizational and social context of the work. Unfortunately, this categorization has seldom been done.

Job types can be characterized as data entry, data acquisition, interactive communication, word processing, or professional.

Consensus statement. The type of work performed has a profound effect on the occurrences of all observed health effects.

Work breaks are a necessity for alleviating discomfort.

Statement. Further separation of job types may be necessary to describe work conditions accurately in relation to some health effects.

Job attitudes associated with VDT work are probably more characteristic of the job than (primarily) the VDT factor. The place of the workers in the organizational hierarchy is of importance in describing a number of stressors — control of work, intensity of work, mental involvement, social contact, etc.

The attitude towards work, while positive in many VDT workers, may be quite different depending on the job type — and related to job monotony, time spent at the VDT, etc.

The optimal pattern of work breaks has not been elucidated.

Comment. In descriptions of the social aspects of VDT work, attention should not be limited to the workplace; considerations of situations outside the work may also be of importance.

The work type and organizational and social aspects may also influence the possibility of recall bias in field surveys. This possibility is of importance in studies in which operators report complaints in interviews or on questionnaires (self-reporting). Such influences may lead to considerable errors when complaint frequencies are estimated — especially in field studies with low response rates.

Short informal breaks may be of major importance in preventing (at least) musculoskeletal problems. Subjective asthenopia occurrence (and possibly that of some other health effects) is apparently increased if reported worktime/day exceeds about 4 h.

Medical and epidemiologic aspects of work with video display terminals

Asthenopia and eye strain symptoms

The symptoms of asthenopia discussed are visual (blurred, double, or flickering vision, etc) and ocular (irritation, pain, red eyes, etc). Unfortunately, some confusion exists as to the exact symptoms included in eye strain, visual symptoms, etc, in various field surveys. This confusion often makes direct comparison difficult.

Consensus statement. VDT work is associated with an increased occurrence of asthenopia symptoms in comparison to similar work performed without VDTs.

The development of asthenopia symptoms is dependent on problematic characteristics of display and workroom lighting. No specific parameter has been fully identified however.

Nevertheless, it is generally agreed that improving display and workroom lighting performance will decrease the frequency of occurrence, probably in connection with changed job requirements.

Statement. Asthenopia symptoms may persist throughout the evening after work. Complaints have been correlated with workroom lighting, glare, screen or character brightness, readability, flicker, reflections, and dry air.

Different studies show major differences as to the occurrence of asthenopia. This variation may be related to different male:female ratios (females having higher asthenopia incidences), the work type (varying trends between data entry and interactive communication reported), length of work periods between breaks, and duration of work (hours/day), as well as differences in display and workroom lighting adjustments. Reported symptom frequencies also differ due to the different survey criteria used (eg, symptoms occurring daily versus occasionally).

Comment. Ocular asthenopia symptoms may be primarily associated with workplace lighting characteristics (glare, brightness of main lighting, shadows, etc) and not with display characteristics, while visual asthenopia symptoms may be more related to the display characteristics.

The relationship between the different display and workroom lighting characteristics are however very complex. Relationships with job requirements and other factors are also incompletely understood.

The wearing of glasses has been correlated with asthenopia symptoms (for both VDT operators and referents).

Effects of the work on measures of eye function

Attention has been focused on the possibility of relating asthenopia symptoms to objectively measured changes, eg, in oculomotor functions. This possibility has generally not been very successful.

Some findings specifically related to asthenopia in VDT operators are of interest.

Consensus statement. No consensus statement is appropriate.

Statement. Temporary changes in accommodation and vergence may occur during work, in both VDT operators and referents. The interpretation of these

findings as results of eye fatigue has not however been established.

These changes have not been shown to be more frequent in VDT operators than in referents.

Comment. This area needs further research, both as to fundamental issues and as to its application to VDT work.

Furthermore, the "temporary myopization" seen in some studies should be further investigated.

Pathological changes in the eyes of operators

Permanent eye damage due to VDT work has been suggested. Primary attention has been given the possibility of cataract formation, while some suggestions on acquired myopia have appeared recently.

The suggestion of cataract formation due to VDT work is based on some case reports.

Consensus statement. There exist neither epidemiologic nor experimental data to support the suggestion that VDT exposure could lead to cataract formation.

Statement. Apart from myopia, no other permanent eye damage due to VDT work is at present suspected or considered.

Comment. The epidemiologic studies on which the consensus statement is based are (formally) not fully conclusive, due to the inadequate worktime spent at VDTs by most study subjects. However, the negative findings of these studies are supported by the lack of (presently known) factors connected with VDTs, which could conceivably be linked with cataract formation.

The possibility of myopia development due to near work (eg, office work, VDT work) cannot be evaluated at present.

Headaches and epilepsy

A number of other effects such as headaches have been discussed in connection with VDT work. It has also been suggested that VDTs may induce photosensitive epileptogenic seizures in sensitive individuals.

Consensus statement. No consensus statement is appropriate.

Statement. Some epidemiologic studies have found an increased occurrence of headaches among VDT workers in comparison to referents, while other studies have failed to do so.

Headaches among VDT workers are probably related to the type of work performed.

Comment. Photosensitive epileptogenic seizures are not likely to occur among VDT operators.

Stress and psychological effects

Several psychophysiological variables have been discussed in connection with VDT work. Specific complaints noted in the discussion are anxiety, depression, irritability, nervousness, increased heart rate, etc.

Consensus statement. These complaints, while frequently occurring in VDT workers (and in reference groups), are linked more to the psychosocial aspects of the workplace than to the VDTs per se.

Statement. There are differences in symptom appearance between different work types, different worksites, different work organizations, etc. No definite pattern can be discerned from the literature however.

Comment. In one study, utilizing both questionnaires and measurements of stress, hormone levels, etc. the following notable influences were seen: VDT operators gave frequent interruptions in VDT processing as one major cause of stress, and adrenaline levels and diastolic blood pressure increased significantly during a 3.5-h interruption.

Skin rashes

A few reports on skin rashes among VDT operators have appeared. In connection with these reports, attention has been focused on electrostatic phenomena of both the VDT and the operator.

Consensus statement. No causal relationship has been established between VDT exposure and the occurrence of facial rashes. The majority of VDT workers appears not to be at increased risk of such disorders.

Statement. A small number of facial rashes has not been adequately explained by other factors. The possibility of a VDT factor involvement remains — supported by experimental findings of increased aerosol deposition on the face of operators in strong electrostatic fields.

Comment. A suggested etiology for the (few) cases of skin rashes that have occurred among VDT operators includes three factors. The first is the presence of a strong electrostatic field, which will increase facial deposition of air contaminants. (The electrostatic charge on the operator may possibly be more important than the charge on the VDT. If so, low humidity is an additional prerequisite.) The second is the presence of an air contaminant capable of causing skin rashes among (some) sensitive individ-

uals. The third is sensitivity of the operator to such air contaminants.

Muscular discomfort

Several studies have indicated the occurrence of various musculoskeletal symptoms among VDT operators. The incidences vary with a number of other variables, both due to the operators' situation and due to the study design.

The musculoskeletal symptoms may be of various types (pain, stiffness, fatigue or tiredness, cramps, numbness, tremor, etc), occur at various locations in the body (neck, shoulder, arms, etc), and occur with varying frequency for each affected operator (daily, occasionally, or seldom/never).

Consensus statement. The occurrence of musculoskeletal discomforts per se does not appear to be specific to VDT operator groups; high levels of complaints can be found in other types of traditional office work (eg, typists). VDT workers have a tendency however to report more centrally located pain (shoulders, neck, possibly upper arms) than non-VDT workers.

The causes of muscle pain in VDT operators are to be found in the constraint of posture and immobilization in specific types of VDT work and workstation design. Correct and adjustable workstation configuration (in connection with possibilities for postural flexibility), variations in job tasks, and short breaks are obvious methods for alleviating these problems.

Statement. Female VDT operators report higher occurrences of musculoskeletal problems than male operators. This finding is probably interrelated with the type of work performed (data entry showing higher occurrences of problems) and duration of work.

Comment. It is possible that the frequency of occurrences (for an individual — reported as often compared to seldom) may be higher among VDT operators. This latter point needs further study however.

No studies have been performed evaluating the possibility of permanent damage due to repeated trauma in VDT workers.

Adverse pregnancy outcomes

The clusters of high frequencies of spontaneous abortion or birth defects that have been reported among a few VDT operator groups in (primarily) the US and Canada have caused considerable apprehension among VDT operators that VDT work may cause adverse pregnancy outcomes.

Consensus statement. VDT/CRT units do not cause birth defects or spontaneous abortion. This conclusion is based on the following rationale:

The frequency by which clusters of adverse pregnancy outcomes appear are consistent with the assumption that female pregnant VDT operators as a group experience normal occurrences of miscarriage or birth defects. The clusters that do appear only represent those few groups with outcomes at the extreme high end of the probability distribution of adverse pregnancy outcomes. (Other groups, according to this assumption, have had lower occurrences, but have not appeared in the debate.) To base conclusions only on those clusters being reported (due to their high occurrences of, eg, miscarriages) is a form of selection bias.

An alternative explanation, suggesting an excess frequency of miscarriages or birth defects, would be viable if any exposure factor could be identified that could conceivably link the VDT/CRT unit or VDT

work to such effects. No such exposure factor has been found. For example, no ionizing radiation has been detected from operating VDT units.

Thus one plausible explanation of the observed clusters has been given — that of chance alone — and no alternative explanation has been found.

Comment. So far, a few epidemiologic studies have been made of pregnancy outcome among VDT operators. The results of these studies do not indicate any excessive occurrence of adverse pregnancy outcome among VDT operators.

Chick embryogenesis has been adversely affected by pulsed magnetic fields in studies reported by one group. So far, the magnetic fields used in this study have not been similar to those from VDTs, either as to the frequency or as to the amplitude. Several research groups are actively investigating this phenomenon.

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Some relations between the electromagnetic measurement units used in this report

Measures related to the energy of a photon

The energy of a quantum (photon) of electromagnetic radiation can be characterized by some interdependent variables, ie, energy, wavelength, and frequency. They are related by the following equations:

$$E = h \cdot \nu \text{ and } \lambda = c \cdot \nu^{-1},$$

where E is the energy, λ is the wavelength, and ν the frequency. With E measured in electron volt (eV), λ in hertz (Hz) and ν in meters (m), the constants h (Planck's constant) and c (speed of light) are:

$$h = 4.1358 \cdot 10^{-15} \text{ eVs and } c = 2.9979 \cdot 10^8 \text{ ms}^{-1} \text{ (in vacuum).}$$

Ionizing radiation is usually characterized by the photon energy (range about 12 eV and above). The frequency of optical radiation (IR, visible, and UV) is normally indicated by the wavelength (range about 1 mm — 100 nm), while that of microwave, radio frequencies, and lower frequencies (Hertzian fields) is indicated by the frequency (0 to about $3 \cdot 10^{11}$ Hz).

Measurements of the electric field strength (E) and the magnetic field strength (B) (or the magnetic field H)

(The relation between $\mathbf{H}$ and $\mathbf{B}$ in vacuum (air) is: $\mathbf{H} = 1/\mu_0 \cdot \mathbf{B}$; $1/\mu_0 = 7.371 \cdot 10^5 \text{ Nm}^2\text{C}^{-2}$.)

The magnetic ($\mathbf{B}$) and electric ($\mathbf{E}$) field strengths at distance r from a conductor with current I are, in principle, given by Maxwell's equations. However, the exact mathematical formulas are complex and cannot be generally computed without some simplifying conditions.

In the near field, where $r \ll \lambda$, the magnetic and electric fields are approximately the same at an alternating current [AC; $I(t)$] and a similar direct current (DC; $I = \text{constant}$). There is no direct and simple relationship between $\mathbf{E}$ and $\mathbf{H}$ (or $\mathbf{B}$); both should be measured separately ($\mathbf{H}$ in amperes per meter and $\mathbf{E}$ in volts per meter). $\mathbf{B}$ is measured in teslas (T, $T = \text{Vs m}^{-2}$) ($1 \text{ T} = 10^4 \text{ gauss}$).

In the far field, where $r \gg \lambda$, the magnetic and electric fields can be described by a plane wave, with the plane perpendicular to the radial distance (= line

of propagation) from the source. The $\mathbf{E}$ and $\mathbf{B}$ field vectors are perpendicular to each other (in the plane). The magnitude of these fields are related by the formulas:

$$|\mathbf{E}| = c|\mathbf{B}| \text{ or } |\mathbf{E}| = \mu_0 c |\mathbf{H}|,$$

where $\mu_0 c = 377 \Omega$ ($\mathbf{E}$ and $\mathbf{H}$ in volts per meter and amperes per meter, respectively).

The demarcation line between the near field and the far field cannot be generally and strictly defined. Several methods have been proposed. The approach used in this text is to define the demarcation line where $r = \lambda$; thus the near field is extended to $r < \lambda$, and the far field to $r > \lambda$. This demarcation is in agreement with the one used by the National Board of Occupational Safety and Health, Sweden, in proposing occupational standards for high frequency electromagnetic fields (5).

At a distance from an electromagnetic source corresponding to that of the operator's from the VDT, near field conditions occur for frequencies below some $3 \cdot 10^8$ Hz (wavelengths above ~ 1 m). These frequencies include radio frequencies and very low frequencies (VLF/ELF) (see table 2 of section I, page 15). In this frequency interval, occupational standards are given separately for the $\mathbf{E}$ and the $\mathbf{H}$ fields.

Far field conditions are considered (at the operator's distance) for all frequencies above some $3 \cdot 10^8$ Hz (wavelengths below ~ 1 m). In this frequency interval, occupational standards can be given in irradiance (power density) $\mathbf{E} \cdot \mathbf{H}$, measured in watts per square meter. (Standards for visible light and ionizing radiation are, however, frequently expressed in other units; see the following discussion.)

In the text, considerable attention has been given the time derivative of the magnetic field, $d\mathbf{B}/dt$. The reason for this is that this parameter is directly related to the magnitude of induced currents in an object placed in the magnetic field. The time derivative in the text is given in teslas per second.

Radiation quantities for ionizing radiation

Ionizing radiation doses, etc, are frequently expressed in röntgen, rem, and rad. These units are being superseded by appropriate SI units, as specified in table 1.

The relationship between the electrostatic charge and the field

In principle, the electrostatic field (E) at distance r from charged object S (eg, a screen) — in the absence of other potentials (charges or grounded objects) — is given by:

$$E = \frac{1}{4\pi\epsilon_0} \iint_S \frac{dq}{r^2} \mathbf{u}_r.$$

For several reasons, this integral is difficult to evaluate. The charge distribution on the screen is not uniform, and the screen dimensions are of the same magnitude as the distance of interest (to the operator). Furthermore, the presence of other charged and/or grounded objects in the room will distort the field.

In the investigations referred to on pages 25–26, the fields were measured in a “standard” situation, and the screen potential (V) was approximately derived by the assumption of

$$V = E \cdot r.$$

This relationship is exact in homogeneous fields — which is not the case in VDT work situations. Here, the derived value for V will depend strongly on the distance r used. The situation can be “normalized” by the use of calibration factors. Thus, unless the measuring procedures and the calibration factors used are known, screen (or body) potentials based on different measurement procedures of the electrostatic fields are not fully comparable.

Measurements of optical radiation

The measurement units used for the “level” of optical radiation require some comments. (The following discussion is limited to the units used in this report.)

UV and IR radiation levels are measured as the irradiance, expressed in watts per square meter.

Visible light levels can be expressed either in radiometric (in watts, etc, energy related) or in photometric terms (in lumens, etc, radiometric levels weighted by the eye's sensitivity to light of different wavelengths). The relations between these parameters are given by the V_λ curves. For photopic vision (strong light), and monochromatic light of 555 nm wavelength, 1 W corresponds to 683 lm. [See, eg, the report of Andersson & Liedquist (2).] The luminous equivalents of phosphors range between some 25 and 530 lm/W. For P_{31} and P_4 phosphors, the values are 230 and 290 lm/W, respectively (3).

The visible light level can be further characterized by the irradiance/illuminance or by the radiance/

Table 1. Relationships between radiation quantities (4).

Quantity	SI unit	Replaced unit	Relation
Exposure ^a	C·kg ⁻¹ ^a	R (röntgen)	1 R = 2.58·10 ⁻⁴ C·kg ⁻¹
Absorbed dose (D) ^b	Gy (gray) (J·kg ⁻¹)	rad	1 rad = 10 ⁻² Gy
Dose equivalent (H) ^c	Sv (sievert) (J·kg ⁻¹)	rem (röntgen equivalent man)	1 rem = 10 ⁻² Sv

^a Applies only to photon radiation. The SI unit relates to the total charge (C) of all ions of one sign produced in 1 kg of air by the ionizing radiation.

^b Defined as energy absorbed per unit mass of a medium; 1 R exposure corresponds to 8.8·10⁻³ Gy.

^c Derived from absorbed dose D by weighting factors Q and N ; $H = DQN$. At present, both Q and N are defined as 1 for photon radiation.

Table 2. Relationships between some of the measurement units for visible light.

	Radiometric units	Photometric units
Specific for the source (distance-independent)	Radiance, in W/m ² , sr	Luminance, in cd/m ²
Specific for the viewer (distance-dependent)	Irradiance, in W/m ²	Illuminance, in lm/m ² (= lux)

luminance. The latter are expressed per unit of solid angle (steradian, sr). [See table 2.]

The radiance can also be weighted with other spectral functions, to determine the level of visible radiation relative to retinal thermal injury (burn hazard function) or retinal photochemical injury (blue-light hazard function) (1). Both of these functions have a strong selection of light around 440 nm (blue light).

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A model study on the occurrence of adverse pregnancy outcomes in clusters of workers using video display terminals

Definition of the problem

A number of groups of VDT operators have been found for which the rates of spontaneous abortion and congenital defects were considerably higher than for the normal population. (See table 16 of section II, page 62.) These findings should be evaluated as to possible explanations — chance, work-related factors, or nonwork-related factors. In this appendix, the possibility of a chance explanation will be examined.

The findings could be due to a combination of (i) chance (the random accumulation of a number of adverse pregnancy outcome cases in a few small groups out of a large number of groups) and (ii) selection bias (the reporting of only these groups with high rates, without normal or subnormal rates in other groups being reported). This suggestion was investigated in a model by the computation of the expected number of groups with a rate of spontaneous abortion of 50 % (or a rate of congenital defects of 35 %) on the assumption that the rate of spontaneous abortions or congenital defects among all VDT workers was the same as that of the general population (null hypothesis).

Model assumptions

Some simplifying assumptions had to be made. The three described variables (population size, group size, and adverse outcome rates) were assigned reasonably well-motivated values for the calculations. Variations in all variables were then made within justifiable limits.

Model population

The estimated number of VDT operators in the US (7 000 000 in 1981, see, eg, the unpublished memorandum of Binkin et al) includes more than 50 % women. In this memorandum, Binkin et al apparently used a pregnancy rate of 20 out of 92 workers during three years for estimates, based on data from the Sears cluster (see table 16 of section II, page 62). The use of a similar pregnancy rate (7 %/year) would mean about 500 000 pregnant women working with VDTs every year in the US.

A pregnancy rate of about 5 % was used in the model, the result being an estimate of 350 000 pregnant VDT operators per year, to be used in the calculations. (This value, which is not expected to be

wrong by more than a factor of 2 in either direction, was used for the present model study only.)

These 350 000 pregnant women were then divided into 29 200 groups with 12 pregnant women in each (spontaneous abortion model), and 35 000 groups with 10 pregnant women in each (congenital defect model). The group sizes were taken from the reported clusters (see table 16 of section II, page 62).

Rates of adverse pregnancy outcomes

The rate of spontaneous abortion was assumed to be 12.6 % (mean of reported data in the study of Axelson (1), with a range of 8.9 to 15.3 %). Binkin et al, in their unpublished memorandum, used 14.4 % as the rate for their estimates, whereas McDonald et al (3) reported a rate of 18.1 %.

Rates of congenital defects appear to be less well defined; rates of between 1.3 and 4.5 % were found in the literature (2, 3, 4). The rate used for the model calculation was 2 %.

Spontaneous abortion

Calculations

The probability distribution of the number of spontaneous abortions in the groups is hypergeometrical (no return), ie, Hyp (350 000, 12, 0.126), which can be approximated with a binomial distribution Bin (12, 0.126).

Results

In figure 1 the expected number of groups per year with a rate of spontaneous abortion higher than x is shown as a function of x . As can be seen, close to 5 400 of the 29 200 groups should be expected to have a spontaneous abortion rate higher than twice the normal rate. The model suggests that 55 groups would be expected to have a rate of spontaneous abortion higher than 50 %, and 6 groups higher than 58 %. (During 1979–1980 (one year), six groups were reported with a mean spontaneous abortion rate of 52 %.)

Variations in the assumptions

Variations in group size and miscarriage rate are shown in table 1. Most combination results show that some groups should be expected to have at least a

50 % miscarriage rate. Only in the case of the largest group size used ($N = 20$) and the smallest miscarriage rate found in the literature (8.9 %), should no group be expected to have a miscarriage rate exceeding 50 %. However, it is *not* implied that the result (in this combination) is a significant deviation from the null hypothesis.

The size of the total population will affect the results only proportionally. If the population size is doubled, the number of expected groups will also be doubled. Increases in the total model population size occur for (i) the inclusion of Canadian data and (ii) an extension of the (model) study time period.

Conclusion

The six groups of high rates of spontaneous abortions which have been reported in the US and Canada during one year (in 1979–1980) are consistent with the hypothesis that the rate of spontaneous abortion among VDT operators is the same as in the general population. Alternative explanations are considered on pages 64–67.

Congenital defects

Calculations

The probability distribution of the number of congenital defects in the groups of the model is hypergeometrical, ie, Hyp (350 000, 10, 0.02), which can be approximated with a binomial distribution Bin (10, 0.02).

Results

The expected number of groups per year with a rate of congenital defects higher than x is shown as a function of x in figure 1. Approximately 6 400 of 35 000 groups should be expected to have a rate of congenital defects higher than 10 %. Six groups are expected to have a rate higher than 35 %. [During 1979–1980 (one year) three groups were reported with a mean rate of congenital defects of about 35 %.]

Variations in the assumptions

Variations in group size and rate of congenital defects are shown in table 2. The majority of the combinations shows that some groups should be expected to have at least a 35 % congenital defect rate. The assumption of a small rate among the total population (1.3–2 %) indicates that the group size is crucial. (See the discussion on group size on page 63.) The failure in some combinations to show that the reported numbers agree or are lower than the expected numbers do *not* suggest that the deviation is statistically significant. (The previous comments made on the total population size are valid also for these calculations.)

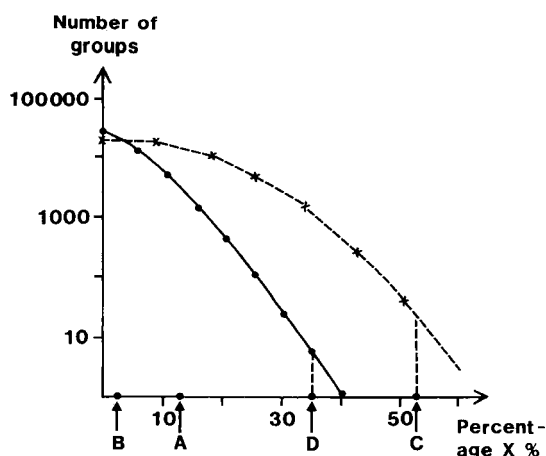


Figure 1. The expected number of groups per year with a frequency of adverse pregnancy higher than x % as a function of x . The rate of spontaneous abortion used for the calculations was 12.6 %, and the group size was 12 — total of 29 200 groups. The rate of congenital defects used for the calculations was 2.0 %, and the group size was 10 — total of 35 000 groups. (A = normal rate of spontaneous abortions used for the calculations, B = normal rate of congenital defects used for the calculations, C = observed rate of spontaneous abortion in six reported clusters in one year (1979–1980), D = observed rate of congenital defects in three reported clusters in one year (1979–1980), x---x = spontaneous abortions, •—• = congenital defects)

Table 1. Calculated number of groups which will be expected to have a frequency of miscarriage higher than 50 %, with variations due to different assumptions.

Assumed group sizes ^a	Rates of miscarriages in all VDT-exposed pregnancies			
	8.9 %	12.6 %	14.4 %	18.1 %
7 (50 000)	279	989	1 479	2 484
12 (29 200)	8	55	110	349
20 (17 500)	(0.04)	1	3	20

^a Number of groups (total population: 350 000 pregnant VDT operators/year) in parentheses.

Table 2. Calculated number of groups which will be expected to have a frequency of congenital defects higher than 35 %, with variations due to different assumptions.

Assumed group sizes ^a	Rates of congenital defects in all VDT-exposed pregnancies		
	1.3 %	2.0 %	4.5 %
7 (50 000)	32	88	556
10 (35 000)	1	6	83
15 (23 300)	(0.01)	(0.01)	4

^a Number of groups (total population: 350 000 pregnant VDT operators/year) in parentheses. (The comments made on the total population size are valid also for these calculations.)

Conclusion

The three groups of high rates of congenital defects which have been reported in the US and Canada during 1979—1980 agree reasonably well with the estimates on the expected number of groups that should appear (according to the model). Thus, chance appears to be a plausible explanation of these findings. Alternative suggestions are considered on pages 64—67.

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A model study on an epidemiologic cohort, examining some complications due to temporal factors

Definition of the problem

In a Canadian epidemiologic study (2, 3) the cohort was defined by hospital attendance due to childbirth or to spontaneous abortion. The women were interviewed in depth on their *first* (previous) pregnancy. (The pregnancy which was the object of these interviews was then *not* the present pregnancy.)

This definition of the study cohort may cause a major methodological error. The outcome of the first pregnancy will influence the probability of and the time interval to the next pregnancy, and this situation will result in selection bias, two possibilities of which will now be presented.

1. All groups where the probability of a second pregnancy is increased will be overrepresented in the study. Conversely, all groups where the probability of a second pregnancy is decreased will be underrepresented in the study.

If the first pregnancy ended in a spontaneous abortion, the probability of a second pregnancy is definitely higher than if the first pregnancy had ended in a normal childbirth. This is one plausible explanation of the surprisingly high rate of spontaneous abortion in the Canadian study: 18.1 % of the total cohort (3). In the literature, spontaneous abortion rates between 8.9 and 15.3 % have been found (1).

If the first pregnancy ended in the birth of a deformed child, it is plausible to assume that the probability of a second pregnancy is lower than after the birth of a normal child. Thus, the rate of congenital defects in the study (3), 4.5 %, may be too low.

As a first approximation, these misrepresentations may be the same for all groups of women in the study cohort and will not affect the relative differences found between different groups in the study. [It is, however, possible that an adverse outcome of the first pregnancy (spontaneous abortion or congenital defect) will decrease the inclination for a second pregnancy, specifically, among women using VDTs.]

These misrepresentations will not be further discussed in this appendix.

2. If the cohort is separated into subgroups depending on a factor (eg, occupation) which increases or decreases with time and these subgroups are further separated into subsubgroups by factors influencing the time interval to the next pregnancy (eg, occurrence of spontaneous abortion or birth of a malformed child in the first pregnancy), an additional compli-

cation will appear. All such subsubgroups, where (i) the second pregnancy tends to appear earlier (compared to the total subgroup) and (ii) the defining factor for the subgroup (eg, occupation) does increase in time, will be overrepresented in the total cohort. Thus the rate of, eg, spontaneous abortion for this subgroup will be too high (compared to the rate in the total cohort).

Due to the cohort definition, the majority of the women whose first pregnancy ended in spontaneous abortion will tend to have had their first pregnancy fairly recently, while women with normal first pregnancies will be contributed to the study from earlier dates, at which time the fraction due to the defining (occupational) factor was smaller. This phenomenon is discussed in detail later. (See table 1 for other subsubgroups.)

Application to an actual study

In the study performed by McDonald et al (2, 3), 14 708 women were adequately interviewed between May 1982 and May 1983 regarding previous pregnancies. Women whose first pregnancy ended with a spontaneous abortion comprised 18.1 % of the total cohort. Among the subgroup (N = 836) working with VDTs, the subsubgroup whose first pregnancies had ended with spontaneous abortion comprised 21.5 %. *For the women included in the study*, this difference (21.5 versus 18.1 %) was statistically significant ($p < 0.01$).

Table 1. Change in observed versus occurred frequency^a as influenced by certain temporal factors of various groups in the study.

Tendency of next pregnancy ^b	Decrease in time of defining factors ^c	Defining factors constant in time ^c	Increase in time of defining factors ^c
Earlier	Lower	Same	Higher ^d
Same	Same	Same	Same
Later	Higher	Same	Lower

^a Change in the observed frequency of the subsubgroup of the cohort due to these factors (represents error in the rate of, eg, spontaneous abortion or congenital defects in the subgroup, when compared to the rate in the total cohort).

^b Time displacement of the next pregnancy due to the outcome of the first pregnancy specified in the subsubgroup (eg, spontaneous abortion or congenital defects), as compared to the displacement of the next pregnancy after a normal childbirth.

^c Defining factors of subgroups, eg, occupation.

^d This situation applies to spontaneous abortion among VDT workers in the Canadian study.

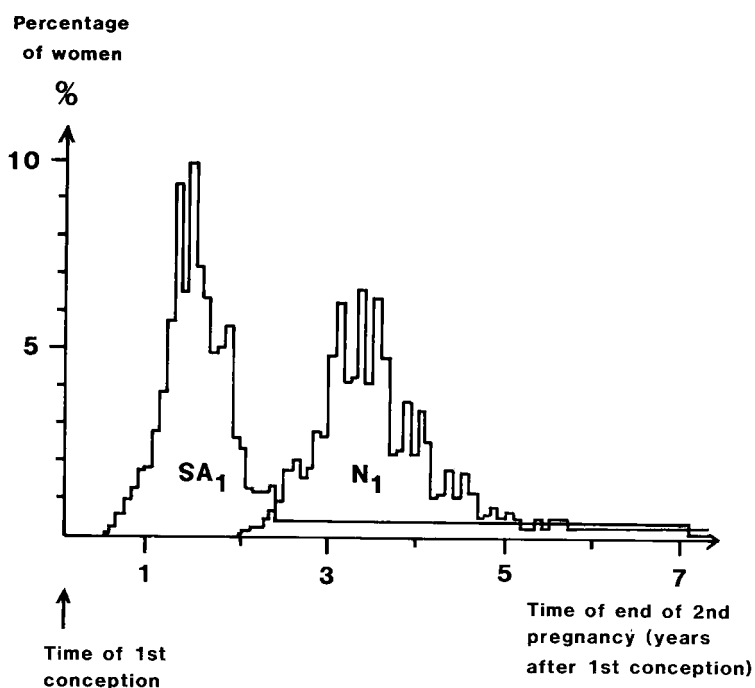


Figure 1. Time distribution of the end of the second pregnancy as influenced by the outcome of the first pregnancy. (For the model assumptions, see page 85.) (N_1 = women whose first pregnancy ended in the birth of a normal child, SA_1 = women whose first pregnancy ended in spontaneous abortion) (Note: no comparison between the absolute sizes of the two groups intended.)

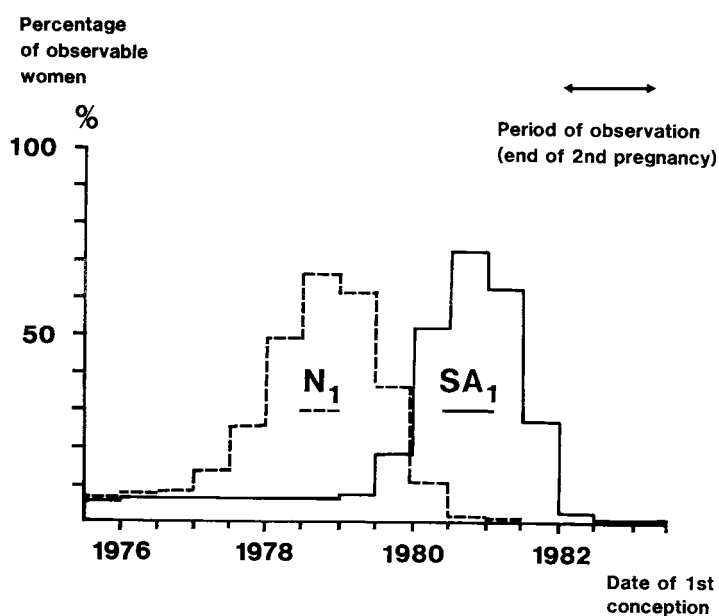


Figure 2. Fraction of women whose first pregnancy began in the period indicated and whose second pregnancy ended between May 1982 and May 1983. (For the model assumptions, see page 85.) (N_1 = women whose first pregnancy ended in the birth of a normal child, SA_1 = women whose first pregnancy ended in spontaneous abortion) (Note: no comparison between the absolute sizes of the two groups intended.)

The increased use of VDTs in many occupations and the shorter time interval between pregnancies when the first pregnancy ended with a spontaneous abortion (1, 3) may, as indicated in table 1, imply that the observed frequency (21.5 %) is too high in comparison to the actual ("true") frequency. Thus it was of interest to investigate whether these findings could be explained quantitatively by the discussed phenomena, on the assumption that the rate of spontaneous abortion (18 %) was the same among women working with VDTs and other women.

Since accurate data on the population under study were lacking in pertinent detail, a model study was performed. This model was then varied to examine the possible variations attainable in the results.

Model assumptions

A number of assumptions had to be made for these calculations to be possible. These assumptions represent "reasonable" estimates and are later varied as a test of the variations in the possible outcomes.

Model population

The model population was 14 000 women, all with their first pregnancy commencing between January 1976 and December 1982 (1 000 per 6-month period), and their second pregnancy no later than six years after the first. No woman in this population had more than two pregnancies. (The last omission is discussed later.) Of these women those whose second pregnancy ended during the time period May 1982 — May 1983 are defined as the model cohort.

Frequency of spontaneous abortion

The frequency was set at 18 % for all women. No difference was assumed between women working or not working with VDTs.

Pregnancy distribution

The distributions are described in figure 1. Data on which to base these assumptions are limited. A Swedish study (1) implies that, of the women spontaneously aborting in their first pregnancies (SA_1), 50 % have started a new pregnancy within six months, and 75 % within 12 months (after abortion). Women with normal childbirth in the first pregnancy (N_1) will wait about two years. For figure 1 this information, together with some further premises, are used to derive a reasonable distribution curve, describing the distribution of women as to the time between the conception of the first pregnancy and the end of the second pregnancy. These women show a clear split into two populations, depending on whether the first pregnancy ended in spontaneous abortion or in a normal delivery. (There is a further splitting of these groups, depending on the outcome of the

second pregnancy — it, however, is not immediately apparent in figure 1.)

In figure 2 the fractions of the women observed in the study (due to their second pregnancy ending between May 1982 and May 1983) are shown; these fractions are strongly influenced by the outcome of the first pregnancy (groups SA_1 and N_1 , respectively.)

Introduction of a third pregnancy, between the first (object of the study), and the last (defining the cohort), for a (small) fraction of these women would result in roughly similar distribution curves for this fraction. The difference between the two curves would be somewhat smaller, and they would be shifted considerably to the right (about three years). In effect, only the SA_1 group would sufficiently contribute to the observed group — in the model. In reality, the N_1 group also contributes, since the cut-off at 1976 is an artifact of the model. Thus introduction of a third pregnancy in the model would result in a (small) overestimate of the impact.

The mass of the curves in figure 1 is the same, 100 % of each group (SA_1 and N_1 , respectively). This circumstance is feasible since the model does not examine the total change in spontaneous abortion due to the cohort definition, but only the relative change between different groups. If a third pregnancy had been introduced, the probability of this "inserted" pregnancy would have to be estimated, since it would determine the contribution from this group. Data on which to base such an estimate were not (immediately) available, though.

For these two reasons, the model was limited to women with two pregnancies only.

Introduction rate for video display terminals

The McDonald study (3) gives VDT occupancy at 4.9 % of all women in the study in 1976—1977 and 14.9 % of all women in 1981. The basic assumption was an exponential curve between these dates and constant occupancy after 1981. This procedure will probably result in an underestimate of the impact of the studied influences, but such an underestimate was judged to be better than extrapolation of the curve after 1981. (The latter procedure may, due to possible market satiation, introduce an overestimate of the impact.) See the following discussion for alternative assumptions.

Calculations and results

In the model the rate of spontaneous abortions in the subgroup exposed to VDTs was computed, on the basis of the preceding assumptions. This computation was done twice, both in the subgroup of the model population (all women) and in the subgroup of the model cohort.

The computations performed are shown in table 2. *Occurred pregnancies* describe the actual first preg-

Table 2. Calculation of the observed versus occurred rate of spontaneous abortion among VDT operators in the model. (N_1 = first pregnancy normal, SA_1 = first pregnancy spontaneous abortion).

Date of 1st pregnancy conception	Time to 2nd pregnancy end if detected by study ^a (months)	Fraction of women observed ^b		VDT operators		Number of spontaneous abortions		Number of observed spontaneous abortions ^e		
		N_1	SA_1	Percent of all women	Number pregnant ^c	SA_1^d	N_1^d	SA_1	N_1	Total
1976 January—June	70—88	0.0669	0.0584	4.16	41.6	7.49	34.14	0.437	2.284	2.721
	July—December	0.0736	0.0662	4.70	47.0	8.47	38.57	0.561	2.839	3.400
1977 January—June	58—76	0.0868	0.0662	5.31	53.2	9.57	43.58	0.635	3.783	4.418
	July—December	0.1370	0.0664	6.00	60.0	10.81	49.24	0.718	6.746	7.464
1978 January—June	46—64	0.2537	0.0664	6.78	67.8	12.21	55.63	0.811	14.113	14.924
	July—December	0.4904	0.0664	7.67	76.6	13.80	62.85	0.916	30.822	31.738
1979 January—June	34—52	0.6731	0.0664	8.66	86.6	15.59	71.01	1.035	49.797	48.832
	July—December	0.6198	0.0754	9.78	97.8	17.61	80.23	1.328	49.727	51.055
1980 January—June	22—40	0.3626	0.1801	11.06	110.6	19.90	90.65	3.584	40.085	43.669
	July—December	0.1083	0.5198	12.49	124.9	22.48	102.42	11.685	11.092	22.777
1981 January—June	10—28	0.0163	0.7288	14.11	141.1	25.40	115.72	18.512	1.886	20.398
	July—December	4—22	0.0011	15.00	150	27	123	17.034	0.135	17.169
1982 January—June	0—16	0.0000	0.2690	15.00	150	27	123	7.263	0.006	7.269
	July—December	0—4	0.0289	15.00	150	27	123	0.780	0	0.780
Sum								65.299		276.614
Percentage of spontaneous abortions in each group						18 %			23.6 %	

^a Time to May 1982—May 1983.

^b See figure 2.

^c Assuming total pregnant group of 2 000 women/year.

^d Under null hypothesis: 18 % of all pregnancies ending in spontaneous abortion.

^e In this model: pre-1981: 9.4 % spontaneous abortion observed, 1981: 95 % spontaneous abortion observed (cf table 1).

nancy events occurring in the model population. These calculations are based on (i) an 18 % incidence of spontaneous abortion for women working with VDTs and other women — thus it is assumed that VDTs will not affect the rate of spontaneous abortion (null hypothesis) and (ii) an increased use of VDTs (as has already been discussed). *Observed pregnancies* are those which should be found by a study similar to the one made by McDonald et al (3), based on the pregnancy-time distribution of figures 1 and 2.

The result is that, while 18 % spontaneous abortions have occurred, 23.6 % spontaneous abortions are observed among VDT operators, due to the over-representation of women with first pregnancies ending in spontaneous abortion.

Variations in the assumptions

A number of variations were made in the model, in both the introduction of VDTs and the pregnancy-time distributions.

The VDT variations were only those compatible with reported data from the McDonald study, ie, 4.9 % in 1976—1977 and 14.9 % in 1981. If this increase was assumed to have occurred momentarily in early 1978 with a constant VDT use thereafter, the observed frequency of spontaneous abortion would be 18.0 %, identical to the occurred frequency. (In effect, this VDT variation is then constant, as far as

these time effects are concerned.) More realistic assumptions (linear, exponential) or extremely late increases in VDT occupancy all result in a higher observed frequency (20.4—33 %).

The pregnancy-time distributions were varied considerably, since those in figures 1 and 2 are based on Swedish data and not Canadian. The mean time difference was, in one case, made as low as 0.5 years (versus 2 years in the Swedish data) and still resulted in an increased observed frequency, 21.8 %. Other assumptions caused the observed frequencies to vary between 20.4 and 34 % (varied VDT occupation figure also being used).

Conclusions

The model has been used in an attempt to quantify the impact of the temporal factors on the outcome of a study similar to that of McDonald et al (3).

The (formally) statistically significant increase in spontaneous abortion observed in women working with VDTs appears to be fully explainable by these time factors. Similar and higher observed frequencies can be found in a reasonable model, still assuming no increase in the real frequency of spontaneous abortion among VDT workers. Conversely, a model which failed to give a substantial increase in observed frequencies required rather unrealistic assumptions on eg, the increase in VDT use.

Such an influence was also discussed (but not quantified) in the paper by McDonald et al (3).

However, if these phenomena are investigated in depth, it appears likely that all the factors experiencing a change in time will be subject to similar influences, the quantity of which will depend on the rate of change of the factor. Thus all factors increasing in time will have observed frequencies that are too high for spontaneous abortions, and probably also too low for congenital defects, compared to the occurred frequencies (see table 1). It was, however, not possible to quantify these effects, except for the VDT group. It is probable that the influence on the subgroups smoking, education, employment, etc, will be less dramatic, due to a slower increase in time.

It is fully conceivable that other factors may exist which will diminish or eliminate the impact of the temporal effects just discussed. Such possible factors do not appear to be easily defined (as witnesses the fairly strong variations in the present model due to

variations in assumptions). Thus the introduction and acceptance of further (ill-defined) factors will, by themselves, introduce substantial uncertainties to the material — and thus make any statistical significance of the material rather dubious.

References

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