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Evaluation of Work Station Design Factors in VDT Operations

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An onsite evaluation was conducted at five establishments using VDTs to examine VDT workstation designs and to compare these designs to recommendations obtained from the literature. Measurements were made of such critical design factors as keyboard height, screen height, workstation illumination, and glare. Illumination levels were generally in the 500 to 700 lx range, and questionnaire data confirmed that these levels were acceptable to most employees. A number of design problems were found in the VDT workstations, including excessive keyboard heights and screen positioning which would require excessive inclination of the head and neck for screen viewing. A majority of the operators surveyed found a number of factors to be bothersome, including screen readability, reflected glare, screen brightness, and flicker. A number of the dissatisfaction parameters were found to be related to levels of somatic (health) complaints.

INTRODUCTION

This paper presents an evaluation of the working environment of VDT operators along a number of dimensions related to physical stress and relates these results to worker satisfaction with the workstation on these same dimensions. The workstation included the immediate area in which the operator works, including all furniture and equipment routinely used by the operator. The evaluation of the environment focused primarily on an examination of factors potentially related to visual and musculoskeletal problems, which have been shown by prior studies to be the health problems most often observed in VDT operators (Grandjean, 1979; Holler, Kundi, Schmid, Stidl, Thaler, and Winter 1975; and Gunnarsson and Östberg, 1977). This examination dealt with the ergonomic aspects of VDT use, an area which has not previously been extensively evaluated in the United States. Cakir and colleagues (Cakir, Reuter, Schmude, and Armbruster, 1978; Cakir, Hart, and Stewart, 1979) have published one of the most comprehensive discussions of the human factors issues related to VDT work and have developed a checklist for the evaluation of VDT workplaces. Based on their findings, they have presented a number of recommendations for the design of both the VDT, the workstation, and the surrounding work environment. In addition, Sweden and Germany have developed standards which specify both voluntary and mandatory design requirements for the VDTs and specify the environmental conditions under which VDTs may be operated. Since no comparable standards exist in the United States, this evaluation relied heavily on the

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European experience and on basic principles of human factors (McCormick, 1976; Poulton, 1970; and Grandjean, 1971). Before describing the actual study, the factors of illumination, glare, contrast, and general workstation design will be discussed.

Proper *illumination* is essential so that both VDT screen and hard copy can be read without undue visual discomfort or fatigue. A wide variety of recommendations exist for lighting levels in VDT operations. The American National Standards Institute (ANSI, 1973) recommends minimum illumination levels of between 750 lx and 1600 lx for a general office environment, depending on the quality of the hard copy used and the type of tasks performed. Cakir et al. (1979) recommend illumination levels between 300 and 500 lx for VDT workplaces, while Östberg (1979) recommends levels as low as 200 lx with supplementary task illumination.

Glare as a factor in VDT operations can be classified with respect to the effect of glare (i.e., disability glare vs. discomfort glare) or the source of glare (i.e., direct glare vs. reflected glare). Discomfort glare is likely to produce a subjective feeling of discomfort in individuals without a significant short-range decrease in performance, whereas disability glare interferes with the ability to distinguish visual objects within the field of view and, hence, causes significant decreases in performance. Reflected glare (sometimes called veiling reflections) is characterized by VDT screen regions with high background luminance levels caused by the reflection of light from other sources. Reflected glare from sources such as overhead lights can also have serious impact upon display legibility. Reflected glare may be either specular or diffuse. The reflections may be perceived by the operator as image(s) (e.g., light fixtures, walls, etc.) or as bright spot(s) on the screen. Because of the curvature of the screen, reflections from high luminance surfaces in much of the work area behind the operator may be visible on the screen. Such reflected glare decreases the effective image/background contrast in portions of the screen. In extreme cases, such glare may "wash out" the image entirely. High levels of reflected glare can approximate the luminance of characters on a display at the low end of the acceptable character luminance range (45-160 cd/m^2) (see Cakir et al., 1979). Excessive reflected glare can increase visual fatigue and can contribute to poor operator posture as operators change position in an attempt to read characters obscured by glare.

Another factor related to visual discomfort and fatigue is the *contrast* between materials being read (e.g., on the VDT screen) and other background sources of high luminance in the work environment. Excessive contrasts within the operator's field of vision can lead to difficulty in reading the display and to visual fatigue due to the repeated need for light/dark adapation. Maximum luminance ratios within the operator's field of vision of between 1:3 and 1:10 have been recommended, with the narrower range being preferred by Cakir et al. (1979).

In terms of *workstation design*, a number of factors can influence worker comfort and health. Some of these are keyboard height, viewing distance, viewing angle, and chair features.

Excessive keyboard height can lead to musculoskeletal fatigue due to the static loading imposed on the operator by the need to keep hands in an elevated position. The Cakir et al. (1979) recommendation for the height of the home row keys in a fixed height work station is 720 to 750 mm. The U.S. Military Standard 1472B (USDOD, 1974) specifies a working surface height of 740 to 790 mm, which approximates the customary keyboard height range for typing in most offices in the United States.

Rebiffe (1969) has recommended that the

angle between the upper and lower arms be between 80 deg and 120 deg and that the angle of the wrist be no greater than ±10 deg. This would require that the keyboard be approximately at or below elbow height, which varies from 605 mm for 5th percentile females to 820 mm for 95th percentile males (Van Cott and Kincaid, 1963). On the other hand, sufficient clearance must be allowed for the operator's legs (645 mm for 95th percentile males) (see Van Cott and Kincaid, 1963). Thus, either a fairly wide range of adjustability or some compromises between leg clearance and keyboard height are necessary. Some authors recommend fairly high working surfaces (keyboards) used in conjunction with footrests.

Proper viewing distance is important in minimizing visual fatigue, and incorrect viewing distance or angle can lead to awkward operator postures. Viewing distance should not be so great that the characters subtend less than the minimum arc required for reading. A viewing distance of 450 to 500 mm, with a maximum of 700 mm, has been recommended by Cakir et al. (1979). A variety of recommendations regarding screen viewing angles have been offered by Dreyfus (1967), Cakir et al. (1979), and IBM (1979). Generally these recommendations place the center of the VDT screen at a position between 10 deg and 20 deg below the horizontal plane at the operator's eye height. Cakir et al. (1979) made the additional recommendation that the top of the screen be below eye height, while Grandjean (1980) recommends that the top line of the display be 10 to 15 deg below the horizontal, with no portion of the screen at a angle of greater than 40 deg below the horizontal.

METHOD

The ergonomic evaluation was conducted on a sample of the VDT workstations at five worksites in the San Francisco Bay area. All workstations were randomly selected, with the exception that at least one sample representative of each equipment type and one sample representative of each major design alternative were chosen. The survey was adapted from a human factors checklist developed for use by NIOSH in a proposed evaluation of letter sorting machine operators in the U.S. Postal Service. The modified checklist sought information in a number of areas, such as work station design, physical environment, and qualitative assessments of the task characteristics. The job design and equipment design portions of the checklist were, in general, limited to data which could be observed directly or elicited through informal interviews. Cakir et al. (1979) have published a somewhat similar checklist.

Five sites were examined. One was an insurance company in which all of the VDT operations examined were clerical in nature. These included data entry, data retrieval for claims review, and data editing. The other four establishments were newspaper operations, at which both professional VDT tasks such as entering and editing stories and compositing and clerical VDT tasks such as answering telephone inquiries regarding circulation and taking classified ads were carried out.

The evaluation of workstation design involved three types of data collection: (1) measurement of illumination and luminance levels, (2) measurement of the physical dimensions of the workstation, and (3) direct observation of work station features which were of special interest. The work station design features noted included adjustability of screen contrast and brightness, quality of display, adjustability of the chair, adjustability of the keyboard and screen position, and design features such as desk characteristics. The work stations examined at each site provided a sample representing the range of VDT types and operating conditions existing at the worksite, and all measurements were made with any equipment adjustments left as they had been set by the operators or other site personnel. Not all measurements were taken at all workstations.

Luminance measures were made with a Photo Research Spectra Mini-Spot Photometer from the position of the operator. The same instrument was used in conjunction with an RS-1 Reflectance Standard to obtain illuminance measures. Luminance was measured in foot-Lamberts, and the values obtained were converted to candelas/square meter (cd/m^2) afterwards. The ratio of the VDT background to the highest luminance region of the operators' general visual field was computed. Illumination levels were measured in footcandles and converted to lux. Measurements were taken at various hours on both clear and overcast days, and a few areas were examined after dusk; thus, some, but not all, areas were observed under high glare conditions with reference to sunlight.

Physical dimensions of the work station were obtained using a carpenter's level and a tape measure. These included the height from the floor to the chair seat pan, keyboard, and screen center and the distance from the home row of the keyboard to the center of the screen. These data, along with data from the literature on median body dimensions for males and females in the United States published by McCormick (1964), Dreyfus (1967), and Van Cott and Kincaid (1963), were used to compute viewing distance and angle measurements.

Photographs were made of a number of workstations to serve as a record of workstation layout and operator working posture. From these photographs judgments were made regarding the nature of operator posture. The postural data serve only to define problem areas, not causes, since it is not possible to determine with complete certainty from the photographs the reasons for observed awkward postures.

A few measurement attempts were unsuccessful, most notably that of character luminance. The investigators were unable to get repeatable measures of character luminance with the equipment used in this field survey. A technique using different instrumentation is being developed for future field studies.

In addition to the workstation evaluations, a questionnaire was distributed to a sample of the employees at each worksite. The methodology used in the distribution and collection of the questionnaire is described in detail by Smith, Cohen, Stammerjohn, and Happ (1981) and will not be repeated here. However, it should be noted that, because the survey was anonymous, it was not possible to link questionnaire responses to specific observed design features. Two blocks of items from this questionnaire are particularly relevant to the human factors evaluation: (1) a 13-item employee rating of workstation design and (2) a 59-item checklist of somatic complaints. Two of the three groups examined by Smith et al. (1981)—professional VDT operators and clerical VDT operators—are of primary interest here, with only a few comparisons being made with non-VDT workers.

In the workstation design section, the respondent was asked to rate parameters affected by workstation design using a five-point scale ranging from "no bother or problem" to "constantly bothersome." The parameters rated in this manner were screen brightness, character brightness, readability, screen angle, keyboard angle, screen height, keyboard height, distance to the screen, distance to the keyboard, screen glare, keyboard glare, noise from the VDT, and screen flicker. Summary statistics were computed by group (professional vs. clerical) for these items.

Another section of the questionnaire presented a list of 59 somatic complaints. The respondent was asked to rate the frequency of occurrence of each complaint during the last year on a four-point scale ranging from "never" to "constantly," with corresponding scale values of 1 to 4. A subset of the 59 items was combined into four scales representing musculoskeletal complaints, visual function complaints, emotional complaints, and psychosomatic complaints. It was not possible to validate these scales due to the small sample size; rather, reliance was placed on the content validity of the scales.

The response range on each of these scales was partitioned to form low-, median-, and high-complaint groups, with each group having an approximately equal number of respondents. The responses to the questions on workstation design ranged over the five-point scale with values from "no bother or problem" to "constantly bothersome." These responses divided into positive and negative responses, with a positive response being that the factor was at least occasionally bothersome. An analysis was conducted to identify relationships between the four scales and the 13 design factors using a chi-square analysis.

RESULTS

Illumination and Contrast

The majority of workstations at the sites examined had illumination levels between 500 and 700 lx; however, levels as low as 300 lx and as high as 1200 lx were observed (see Table 1). At one site, the employees were allowed to determine whether the overhead lights in their area would be on or off, giving them some group control over illumination levels. Certain areas at each site were adjacent to windows which had the potential to create excessive illumination levels in periods of bright sunlight. At one site, windows were equipped with curtains which if properly used would have eliminated excessive illumination from the windows; at a second site the windows were equipped with tinted filters which somewhat reduced transmitted daylight. The range of individual station maximum simple luminance ratios (the ratio between low and high luminance field at that workstation) at the sites visited was between 1:2 and 1:60.

TABLE 1

Illumination Levels at Workstations

Level (lx)	*Number of Workstations*
0–299	0
300–500	6
501–700	39
701–1000	2
>1000	5

Note: Cakir et al. (1979) recommend a range of 300 to 500 lx. Other recommendations, both higher and lower, exist.

Glare

Potential discomfort glare sources existed at 46 of the 53 work stations surveyed, particularly when the operator would shift his or her direction of viewing. The glare sources included windows and light fixtures, with luminance levels of up to 2100 cd/m². Although the windows at one site were equipped with curtains, in many cases these curtains were left open. It should be noted that in offices with windows both illumination and glare levels can be affected by the weather and the time of day; thus, although severe glare was noted in only one office, a potential glare problem existed in any of the offices with at least one window exposed to direct or reflected sunlight.

Reflected glare was present in most of the VDT screens surveyed; this reflected glare generally consisted of reflections from windows and overhead lights. At the insurance company, maximum and minimum luminance measures were taken of blank VDT screens to give a measure of reflected glare at that site. These data are given in Table 2. The maximum reflected luminance levels on the VDT screens ranged from 3 to 50 cd/m², and the investigators as well as operators who were questioned had difficulty reading cer-

TABLE 2

Screen Background Luminances

Luminance Ratio	Number	Maximum Background Luminance (cd/m^2)	Number
<1:3	12	<10	3
1:3–1:5	4	10–15	4
1:5–1:10	3	16–20	9
>1:10	3	21–45	4
		>45	2

tain screens which had high reflected glare levels. Of the 53 screens evaluated at all sites, nine, or approximately 17%, had reflected glare levels which could make reading characters on parts of the screen difficult.

Techniques for limiting reflected glare were in use at many of the workstations examined. The majority of the VDTs had etched glass screens (to eliminate specular reflections) supplied by the manufacturer, while a few were equipped with film coatings also supplied by the manufacturer. Many employees at one of the sites had fashioned makeshift hoods from newspaper, cardboard, and other materials. A few VDTs were equipped with micromesh honeycomb-type glare screens. The thin film coatings and micromesh honeycomb filters appeared to be successful in reducing reflections, but tended to smudge and collect dust, respectively. The makeshift hoods were somewhat effective, but many, particularly the deeper hoods, limited the operator's ability to adopt comfortable working postures. It is not possible to make a global recommendation from these limited data regarding methods to use in reducing reflected glare, especially as the specific nature of the job may have an impact.

Display Legibility

Image quality was judged by the researchers conducting this evaluation. No jitter or flickering was observed on any of the screens examined, nor was any flicker reported by a small sample of operators when questioned; however, the perceptibility of flicker varies with illumination, screen luminance, whether foveal or peripheral vision is used, and operator sensitivity. In a few cases, slight blurring of characters was observed at the screen edges. However, it was judged that the character blurring observed was not sufficiently pronounced to interfere with the operator's ability to readily distinguish characters. The displays all used a minimum 5 × 7 dot matrix to form character blocks approximately 3.0 mm in height. This character size corresponds to a recommended minimum 5 × 7 dot matrix and range of recommended height of 2.6 to 4.2 mm (Rupp, 1979). No characters of unusual design, which would pose additional reading problems, were observed by the investigators. Many, but not all, of the VDTs had brightness and contrast controls accessible to the operator.

Workstation Design

Several types of work stations were observed: (1) specifically designed workstations which had an inset area for placement of the keyboard and home row heights between 760 and 775 mm; (2) units in which the VDT screen and keyboard sat on a standard desk, with home row heights of 820 to 830 mm; (3) units in which the VDT screen and keyboard sat on a revolving platform somewhat above desktop height and between two desks, giving keyboard heights from 840 to 870 mm; (4) units in which a VDT unit sat on a typewriter stand or shelf either at a workstation or between two workstations, giving keyboard heights from 720 to 840 mm; and (5) units at which the VDT sat on a special stand, giving a keyboard height of between 760 and 810 mm. In the first three groups, the VDT screen and keyboard were in separate housings, which would in principle allow the keyboard and screen to be positioned separately for the comfort of the operator. However, for the other two groups, the VDTs did not allow separate positioning of the keyboard and screen, and, in many cases, these units required excessive visual angle for tall operators. Keyboard heights are given in Table 3, and the estimated viewing distance and viewing angles for male and female operators of median dimensions at the sites visited are summarized in Table 4. Many of the viewing angles were larger than recommended, especially for male operators of greater than median dimensions. However, as Table 4 shows, the viewing distances were all in the acceptable range (450 to 700 mm). Varying kinds of operator chairs were present at these sites. However, most were standard typist chairs with, at minimum, adjustable seat pan height and back support. Some chairs had adjustments for seat pan angle and backrest tension, while a few were straight-backed chairs with no adjustment features. The observed seat pan heights ranged between 420 mm and 510 mm, with a mean of 470 mm. Most of the chairs could be swiveled and moved on casters to enhance operator freedom of movement. Few chairs had any form of armrest. All workstations examined had adequate knee room.

TABLE 3

Keyboard Height (Floor to Home-Row)

Keyboard Height (mm)	*Number of Stations*
0–720	0
721–750	3
751–790	23
>790	27

Note: Keyboard height ranges recommended in the literature are generally around 720 to 750 mm (Cakir et al., 1979). The U.S. Military Standard recommends a *working surface* height of 740 to 790 mm (USDOD, 1974).

Questionnaire Findings

The questionnaire yielded some interesting data regarding the employees' perceptions of their workplaces. In response to a group of questions concerning the office environment, most employees (63%) rated summer temperature and level of distraction (64%) as too high, while a slight majority were satisfied with the illumination, and a slight plurality (41%) felt the winter temperature was too low; no significant differences were observed between VDT and non-VDT employees for these latter factors. Responses to a group of questions regarding lighting indicated that most employees were satisfied with the workstation (53%) and background (63%) illumination levels. A significantly larger proportion of the VDT operators (80%) than non-operators (62%) reported glare from the workstation lighting, and more VDT operators (44% vs. 30%) reported shadows cast by background lighting. Of all employees responding, 38% reported their chairs were comfortable, while 32% reported them to be just adequate, and 30% uncomfortable. However, 70% reported their chairs to be at correct height. The VDT and non-VDT groups did not differ significantly in their ratings of their chairs, either for comfort or correctness of height; however, the clerical VDT workers found their chairs significantly less comfortable than did either the professional VDT workers or the non-VDT operators ($p < 0.01$, chi-square).

Another group of questions dealt with how often VDT operators found various aspects of their workstations bothersome (Table 5). In order of prevalence (i.e., the respondent finding the condition bothersome at least oc-

TABLE 4

Screen Viewing Angle and Distance for Male and Female Operators of Median Dimensions

Sex	Viewing Angle (deg)	Number	Viewing Distance (mm)	Number
Males	0–9	0	0–449	0
	10–20	8	450–500	0
	21–30	28	501–700	45
	>30	10	>700	1
Females	0–9	2	0–449	0
	10–20	25	450–500	4
	21–30	14	501–700	42
	>30	5	>700	0

Note: Recommendations in the literature generally range between 10 deg and 20 deg for viewing angle and 450 to 700 mm for viewing distance.

casionally), the most frequent complaints were screen glare (85%), character brightness (70%), readability (69%), flicker (68%), and screen brightness (62%). The rest of the factors examined were reported as bothersome by fewer than half of the employees.

Table 6 shows the relationship between the somatic complaint scales and employee dissatisfaction with workplace design parameters. For both professional and clerical VDT workers, a significant relationship existed between visual function complaints and the employee rating of the workplace design parameters, including glare, screen angle, noise from the VDT, and screen flicker. Data from the clerical VDT workers show a relationship between the rating of the screen height and visual function complaints, while the data for the professional VDT workers show a relationship between visual function complaints and the rating of screen brightness, letter brightness, and readability. For the professional VDT operators, several factors were shown to be related to musculoskeletal

TABLE 5

Percentage of VDT Operators Rating Workplace Design Parameters as Bothersome

	Often Bothersome	Occasionally Bothersome	No Bother or Problem
Screen brightness	18	43	38
Character brightness	23	47	30
Readability	28	41	31
Angle of screen	18	26	55
Angle of keyboard	14	25	61
Screen height	27	26	57
Height of keyboard	13	24	63
Screen distance from operator	13	22	65
Keyboard distance from operator	10	23	67
Glare off screen	45	39	15
Glare off keyboard	9	17	74
Noise from VDT	14	20	66
Flicker	26	41	32

Note: Rows do not sum to 100% due to rounding error.

TABLE 6

Percentage of VDT Operators Who Rated Workplace Design Features as Bothersome by Somatic Complaint Status[1]

	Professional Employees (N = 112)			Clerical Employees (N = 80)		
	Low Complaints	Medium Complaints	High Complaints	Low Complaints	Medium Complaints	High Complaints
Musculoskeletal Complaints Versus						
Screen angle	26	41	56			
Screen height	26	35	59			
Screen glare[2]	34	56	63			
Screen flicker	50	64	84			
Visual Function Complaints						
Screen brightness	38	57	80			
Character brightness	49	68	90			
Readability	51	75	84			
Screen angle	30	41	61	26	27	70
Screen height				32	23	64
Screen glare[2]	27	42	87	17	42	55
Noise from VDT	14	21	45	26	43	61
Screen flicker	49	70	90	45	65	84
Emotion/Mood Complaints						
Screen brightness	37	54	75			
Screen angle	23	51	50			
Screen height	23	51	55			
Screen glare[2]	30	63	50			
Noise from VDT	7	30	38			
Screen flicker	50	68	83			

[1] Significant at $p < 0.05$ or better by chi-square test.
[2] Figures for screen glare represented the percentages of the operators who rate glare as at least "often bothersome" as opposed to "occasionally bothersome" or no bother.

and mood complaints; but no significant relationships were found for psychosomatic complaints in either VDT group.

DISCUSSION

The purpose of this evaluation was to characterize the environmental and workstation design features of VDT operations to pinpoint potential sources of strain and to be able to relate these factors in a general way to employee somatic complaints. Smith et al. (1981) discuss the somatic complaints of VDT operators in more detail. In terms of characterizing the work environment, the human factors evaluation showed physical workstation design to be less than optimal in a number of respects. The keyboards were almost all placed higher than would be optimal for any but relatively tall operators, while in many cases the VDT screen heights were too low for a tall operator. In some cases, this was the result of placing the VDT units on standard office desk tops. In all of the workstations examined, the minimum keyboard and screen heights were set by the design of the (nonadjustable) furniture, and in only a few cases had the keyboard been raised by the operator (e.g., by placing stacks of paper under the keyboard). For many workstations, the screen and keyboard were attached, fixing the screen height in relation to the keyboard; however, screen height had been raised for operator preference at some workstations at which the keyboard and screen were not attached. It is interesting to note that relatively few operators rated the keyboard or screen heights as bothersome, compared to other factors. It is worthy of note that these problems, particularly keyboard height, are not unique to VDTs, and the operators interviewed indicated that they felt these parameters were fixed and that they did not have any expectations that the parameters could be changed.

Most of the VDT operators rated their chairs as at least adequate, and no significant differences in this rating were found between VDT and non-VDT groups. As no major differences were observed in the types of chairs used by the different groups, differences in task demands are one likely explanation for the differences between the ratings by the clerical VDT workers and those by the other two groups. For instance, the VDT clerical jobs apparently offered less opportunity to get up and move around than did the jobs in the other two groups.

Measurements and observations at the worksites determined that the ambient illumination levels were generally within a range suitable for VDT use, and most VDT operators and other employees reported the lighting levels as being acceptable. VDT operators were significantly more likely to report glare produced by the workstation lighting and shadows produced by the background lighting than were non-VDT operators. In addition, VDT operators reported more glare from background lighting and more shadows from workstation lighting than did other workers. Approximately 85% of the VDT operators reported that screen glare was bothersome at least occasionally. Thus, while ambient illumination levels were apparently generally satisfactory for both VDT and non-VDT tasks, VDT operators were less satisfied with other aspects of the workplace lighting than were other workers, presumably because of the special visual demands presented by the VDT task.

Most VDT operators found glare, screen and letter brightness, flicker, and readability bothersome. The reports of the VDT operators were verified by measurements of the glare, since reflected glare in the VDT screens was observed at every worksite. The dissatisfaction reported with character and screen brightness may also be related to reflected glare. While transmitted luminance levels of the screen were not accurately measurable with field equipment used in this study, the importance of this parameter is demonstrated by the level of reported VDT operator dissatisfaction with screen brightness. Procedures and instruments for making the required measurements are currently being developed to allow for further examination of this factor in detail in future studies.

The questionnaire did not tap information regarding the specific nature of the brightness, flicker, and readability problems perceived by the operators; thus, a number of different phenomena may have contributed to the responses to these items. It is worthy to note that most of the VDTs had controls for adjustment of brightness, and, thus, the complaints regarding character brightness may have been connected with difficulty in adjusting the brightness to ambient lighting and glare conditions. Readability and flicker problems were also reported by the VDT operators as bothersome; however, no objective measures of these parameters were taken, and subjective evaluations by the investigators did not indicate that a large problem was likely. Moreover, it must be emphasized that a variety of other factors play a role in the perception of flicker and in the readability of the display (Gould, 1968, and Grandjean, Baschera, Marti, and Weber, 1977). In terms of display readability, the subjective investigator assessment was concerned mostly with character style, for which no standards exist (Snyder and Maddox, 1980), but the operators may have also been responding, in part, to the problem with glare and luminance mentioned above.

While it is not possible to infer causality, the data relating somatic complaints to workstation parameters suggest that in both VDT respondent groups a relationship exists between the worker rating of several workstation design parameters (glare, noise from the VDT, screen angle, and flicker) and the prevalence of somatic complaints related to vision. Among the clerical VDT workers, the rating of VDT height was related to visual function complaints; and, among the professional workers, several parameters (screen glare, screen angle, and flicker) were related to several of the complaint scales. In all of these cases, high levels of somatic complaints appeared to be associated with higher levels of worker dissatisfaction with the parameter than were low levels of somatic complaints. A number of differences between the two groups, including sample size, differing task demands, differences in workstation design and equipment, and demographic differences, may in part account for the varying findings.

CONCLUSIONS

This evaluation was conducted at a limited number of worksites, which cannot be assumed to be representative of all VDT workplaces, and, therefore, it is not appropriate to generalize these results to other VDT operations. However, a number of conclusions appear to be warranted in regard to these sites: (1) glare, screen luminance, and readability were bothersome to VDT operators, and objective measures demonstrated glare to be a problem; (2) physical workstation design was generally less than optimal with respect to such parameters as keyboard height, screen position, and chair design, but operators generally perceived these aspects as less bothersome than those not related to visual problems; (3) lighting was generally within the recommended ranges, and most VDT operators and other workers rated illumination levels as "about right." However, the VDT operators were significantly more likely than the others to rate the lighting as producing glare. These conditions can be related to operator health complaints, particularly those concerning visual and musculoskeletal problems.

The factors considered in this investigation can thus be divided into several groups, based on the results of the worksite evaluations and the questionnaire. Measured illumination levels were generally within the recommended range, and most of the respondents rated the lighting levels as approximately correct. Screen glare was measured at only one site, with some measured levels appearing to be quite high; and, in the questionnaire, 85% of the respondents reported at least occasional problems with glare. This rating of glare was shown to be related to certain groups of somatic complaints. Screen brightness, readability, and flicker were not measured at the worksite because of methodological difficulties, but these were reported as bothersome by at least half of the operators, and some significant relationships to somatic complaints were identified. Keyboard height and screen height (viewing angle) were frequently found to be nonoptimal in worksite measurements, but they were rated as bothersome by less than half the respondents. Screen height, on the other hand, was related to some measures of somatic complaints. Angle of the keyboard, screen distance from the operator, keyboard distance from the operator, and glare off the keyboard were not identified as major problems during worksite evaluations, nor were they rated as bothersome by a majority of the operators. Screen angle and noise from the VDT were not measured, nor were they rated as bothersome by a majority of the operators, but they did show significant relationships to somatic complaints. Since screen angle can affect screen glare levels, it is suggested that this feature be measured in future studies.

Based on the results of this investigation, it is recommended that future human factors evaluations of VDT workplaces include measurements of:

(1) Illumination levels
(2) Glare, particularly glare on the VDT screen
(3) Screen flicker, background and character brightness, and readability
(4) Workstation dimensions including keyboard and screen height, screen angle, knee room, and chair dimensions and characteristics
(5) Noise and other environmental measures, with particular reference to noise from the VDT
(6) Analysis of the VDT and other tasks involved, and employee questionnaires, where necessary

For some of the parameters listed above, such as flicker, adequate field measurement techniques are not readily available, and considerable ingenuity will be required in developing appropriate measures. Further research aimed at determining the relationship of these parameters to performance and health effects is also necessary.

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