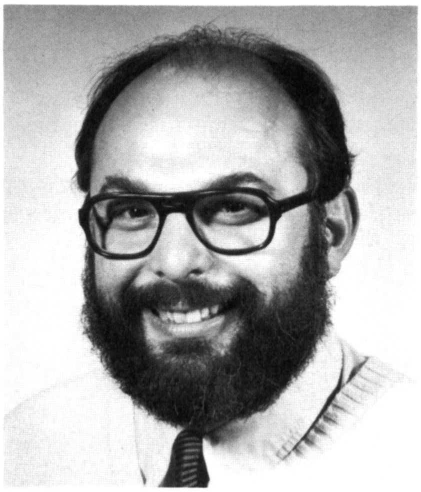
Video Display Terminals
The Relationship Between Ergonomic Design, Health Complaints and Operator Performance

ABSTRACT

An experimental simulation of a VDT entry task was conducted during five three-hour test sessions in which subjects worked under ergonomic conditions alternating between good and poor features as defined by adjustments of working and seating surfaces, lighting, and glare. Performance measures were taken during each session and a battery of psychophysical/physiological measures and subjective complaints were taken before and after each work session. Preliminary results indicated a 24.5% improvement in performance as well as a decrease in musculoskeletal complaints attributed to good ergonomic design characteristics.

Quietly, without our really being aware of it, the office has become the predominant working environment in the United States. By 1980, office workers comprised over 50% of the workforce and their salaries comprised 50% of the operating budgets.[1] However, as Rotolo also points out, this relative domination by the office worker of all occupational categories, has been accompanied by a poor record of productivity. For the period 1960-1970, manufacturing productivity rose 83% whereas office productivity was a mere 4%. Consequently, if we consider both factors in combination—large cost and poor productivity—we see an inevitable set of pressures towards a solution of this dilemma in the form of automation of office functions. We are, at this moment, in midst of this automation process; all around us we see traditional office functions—filing, typing, bookkeeping, telephoning—being replaced by data base systems, word-processing, and electronic communications. At the focus of all of this automation, is the primary interface or communication link between person and computer: the video display terminal (VDT). This device, the VDT (variously labeled a VDU or CRT) is in the process of replacing the typewriter as the ubiquitous symbol of the office. Indeed, Guiliano[2] estimates that by 1990, 40-50% of all U.S. workers will spend at least part of their workday utilizing such a device.

Video display terminals have been in relatively widespread use by workers who are not computer professionals for about 10 years. In that time, we have seen a considerable degree of concern raised about the health and safety impact of VDTs on people who work with them. These complaints have taken a variety of forms and involved a variety of potential causes; however, visual and musculoskeletal symptoms seem to be most consistent in generating concern.[3] A number of field studies from around the world indicate levels of incidence of symptoms of visual fatigue and musculoskeletal stress at 50% or higher in samples of VDT workers; moreover, these levels tend to be higher than symptom levels of workers doing similar kinds of work but not utilizing VDTs.[4-7] At the same time, it appears from some of these studies that a major source of such complaints potentially lies in the lack of good ergonomic design which has tended to characterize these workplaces. However, the linkage between ergonomic design and health complaints have been inferred rather than directly demonstrated; there has been a lack of empirical evidence associating specific ergonomic deficiencies with particular health complaints. The present investigation is the first in a series of laboratory expriments which will attempt to obtain such evidence.



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INTRODUCTION

The logic of the experimental approach is to confront the ergonomic problem in an extreme form. Consequently, we have designed a simulated data entry/maintenance work task

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in which operators alternated between two workstations which differed on a number of critical ergonomical design criteria. Objective measures of visual performance, blood pressure, and subjective health complaints were taken before and after each session; as well as speed/error measures which were taken during the session. Although this study deliberately confounds individual ergonomic factors within a global "best case" vs. "worst case" comparison, the results should be useful in establishing, within a systems perspective,[8] the efficacy of good ergonomic design in VDT workplaces. In addition, it should provide a baseline for future, more analytic studies utilizing the same basic methodology.

The present paper is a preliminary report on results obtained from this investigation.

METHOD

SUBJECTS

Thirteen trained (40-55 wpm) typists with no prior VDT experience were recruited from an employment agency specializing in temporary clerical help. Each subject received a physical and ophthalmological screening examination prior to participation in this study. Accordingly, all subjects were in general good health, with no histories of hypertension and/or musculoskeletal disorders, corrected visual acuities of 20:20, and no evidence of presbyopia. Twelve of the subjects were female; one was male. Median age was 26, with a range of 19-35 years; median height was 162.6 cm, with a range of 144.8-171.8 cm; and median weight was 61.9 kg with a range of 49.1-74.5 kg.

APPARATUS

Workstations: Equipment of ergonomic relevance in work stations included an IBM Synergetix adjustable VDT work station and task chair; Wrightline ETS 2000 adjustable VDT work station, inline copy holder, and wrist rest; an Armstrong Tascan parabolic lighting fixture, a Polaroid CP 70 contrast enhancement filter; an Acme-Lite music stand lighting fixture; and two DEC VT-100 VDTs.

Task Simulation and Analysis: The data entry/maintenance tasks were simulated using a Corvus 5.5 megabyte hard disk/multiplexer in conjunction with three Apple II microprocessors. Two of the microprocessors were individually slaved to a VDT, and each served to control a single work station. The third microprocessor was used for off-line data analysis and other utility functions.

A Panasonic closed circuit video tape recording system was used to monitor each subject, as well as to record portions of each session on videotape for further postural analysis.

Psychophysical/Physiological Measures: An Optronix Series 200 self-calibrating Vision Tester was used to measure spatial and temporal contrast sensitivity functions. A Titmus Vision Tester, used in conjunction with a pair of specially designed -1.25 diopter lenses, was used to measure near acuity and lateral phoria at a distance approximating that of typical VDT work.Systolic and diastolic blood pressures were taken with a Sphygmetrics Infrasonde Model SR-2 automatic blood pressure recorder. A Rosenbaum Near Point card, along with a metric rule, were used to measure near points of accommodation and convergence. Finally, a 10-item discomfort questionnaire was presented to each subject on their work station VDT. Questionnaire items are indicated in Table 2.

DESIGN

Subjects were scheduled, two at a time, for a five-day work week, during which they worked at their simulated entry/maintenance tasks for three hours per day without rest breaks. The first day of each week served as an orientation/training session. Each subject then worked for two days in an ergonomically best case environment and two days in an ergonomically worst case environment. Pairs of subjects were assigned to best and worse case conditions in a counterbalanced order (ABBA or BAAB). Each three-hour work session was preceded and followed by a 30-minute testing period during which subjective complaints and objective psychophysical/physiological measures were taken.

PROCEDURE

Ergonomic Manipulation: Each work station was set up in a 230 x 193 cm enclosed room containing an adjustable work station, chair, VDT, overhead lighting fixture, and a TV camera. In the best case work station, the parabolic lighting fixture was employed, along with a music stand light—mounted on an in-line copy holder—to provide additional task lighting for the hard copy. The chair was gas-cylinder adjustable in both seat pan height and back tilt, with adjustable lumbar support. A wrist rest was also provided. Chair, keyboard height, and screen height were individually adjusted such that subjects under best case conditions were in a posture with their feet flat on the floor, lumbar region of the back supported, elbow height approximately at the level of the home row of the keyboard, and screen viewing angle at around 20 degrees of screen center. A contrast-enhancement filter was placed over the face of the terminal screen, and the contrast control increased such that a character-screen contrast ratio of approximately 550 lux.

In the worst case condition, a standard non-adjustable office chair with limited lumbar support was utilized. No wrist rest or copy holders were utilized. Adjustable work stations were deliberately maladjusted such that forearm angles approximated 45 degrees from the horizontal, and screen viewing angle approximated 30 degrees to screen center. Glare conditions were created by removing the diffuser from a 4 tube bank of overhead fluorescent lights and lowering the contrast control on the VDT. This resulted in a character-screen contrast ratio slightly better than 1:1, with an illuminance value of 1081 lux on the hard copy. (It should be pointed out that these conditions are similar to many actual work stations observed in the field.)

Task Manipulation: The subjects' task involved alternating between data entry and file maintenance. During the data entry phase, subjects entered information from an 11 field "chemical stock inventory" from paper copy into the computer. After 20 such files, the task switched to file maintenance. Under this condition, a completed file was displayed in which 8 of the 11 fields contained errors. Subjects were then required to compare screen content against paper copy and correct the errors.

Following completion of each file, the subject's performance on that file was analyzed on-line, in terms of keystrokes per minute and errors per minute, by the third Apple II microprocessor. (Four different types of errors were measured; however, for the present discussion, an error is defined as one or more incorrect entries in a given field.)

A base line level of performance in terms of keystrokes per minute was obtained during the first training day. (During this period, ergonomic parameters in the two workstations were equalized as much as possible.) Following training, an incentive pay system was described to the subject such that he/she would receive $1.00 per hour for each 10 keystrokes per minute over baseline, but would be penalized $.40 per hour for every one error per minute. Performance feedback was given to each subject at the middle of each three hour session and at the beginning of the following session.

Pre- and Post-Session Assessment: A half hour assessment period preceded and ended each work session. The assessment began with the measurement of contrast sensitivity functions; first temporal (4, 10, 20 and 30 Hz), then spatial (0.5, 3.6, 11.4 and 22.8 cycles per deg.) using the Optronix Vision Tester. Next, the subjects' near points of accommodation (for each eye) were assessed in terms of the point at which the 20:20 line on the test card blurred. Near point of accommodation was estimated in terms of the distance at which diplopia occurred. Intermediate field acuity (80 cm) and lateral phoria was measured with a Titmus Vision Tester using a -1.25 diopter lens. Systolic and diastolic blood pressure were then measured with the Infrasonde automatic blood pressure recorder.

The subject then moved to the workstation where a 10-item physical discomfort questionnaire was administered. The questionnaire included three items related to visual complaints, six items related to musculoskeletal complaints, and one item related to headache. Subjects were asked to respond in terms of the extent to which discomfort was experienced at the present time or within the past 30 minutes. Extent of discomfort was indicated by the subjects' moving a cursor from the extreme left of the screen (no discomfort at all) to the right of the screen at column 50 (considerable discomfort).

The post-session assessment period

TABLE 1

INCENTIVE PAY BY CONDITION AND DAY AND PERCENTAGE INCREASE OF BEST CASE (B) OVER WORST CASE (W) WHERE %=100 (B-W)/W

	Days 1 and 2			Days 3 and 4			Average		
Subject	Best Case	Worst Case	%	Best Case	Worst Case	%	B	W	%
3	2.19	3.53	−37.96	5.31	4.16	27.64	3.75	3.84	−2.60
4	2.77	1.32	109.85	3.06	2.99	2.34	2.92	2.15	35.80
5	1.99	2.67	−25.47	4.33	3.47	24.78	3.16	3.07	2.93
6	1.91	2.61	−26.82	3.90	3.10	25.81	2.91	2.86	1.74
7	2.01	1.43	41.55	2.28	2.98	−17.99	2.15	2.10	2.38
8	1.64	1.84	−10.87	2.70	2.11	27.96	1.87	1.06	17.92
9	2.08	0.76	173.67	2.53	1.79	41.34	2.30	1.27	81.10
10	2.66	2.67	−0.37	4.30	3.21	33.96	3.48	2.94	18.37
11	1.49	0.63	136.51	−1.81	1.45	24.83	1.65	1.04	58.65
13	1.71	0.51	235.29	−2.59	2.35	10.21	2.15	1.43	50.34
14	2.08	2.87	−27.53	−3.87	3.16	22.46	2.98	3.02	−1.32
15	2.80	0.76	268.32	−3.13	3.65	−14.24	2.96	2.21	34.30
17	2.39	1.14	109.65	−2.92	3.36	−13.09	2.66	2.25	18.22

TABLE 2

AVERAGE POST-SESSION MINUS PRE-SESSION DIFFERENCES IN EXTENT OF SYMPTOM CHECKLIST COMPLAINTS, WHERE %=100 (WORST-BEST)/BEST

Question	Days 1 and 2			Days 3 and 4			Average		
	Best	Worst	%	Best	Worst	%	Best	Worst	%
1. Blurred vision	−2.62	0.62	−123.66	0.08	−1.00	−1350.00	−1.38	−.81	41.3
2. Eye irritation	−0.15	3.46	2407.67	2.23	2.77	24.21	1.04	3.11	199.04
3. Eye fatigue	2.69	6.00	123.05	6.00	2.08	−65.33	4.34	4.04	6.91
4. Pain in arms	6.00	8.15	35.83	4.54	7.54	66.08	5.27	7.84	48.77
5. Pain in legs	3.69	3.15	−14.63	3.15	5.46	73.33	3.42	4.31	26.02
6. Pain in neck, shoulder and upper back	8.54	14.85*	73.88	11.31	12.31	8.84	9.92	13.58	36.89
7. Pain in wrist, hands, and fingers	6.15	6.00	−2.43	6.38	5.92	7.71	6.26	5.96	−4.79
8. Pain in lower back	10.00	17.15*	71.5	9.39	9.85	4.90	9.69	13.5	39.31
9. Loss of sensitivity in fingers	0.62	0.54	−12.90	0.00	0.00	0	0.32	0.27	−15.62
10. Headache	1.54	4.39	185.06	1.15	2.23	93.91	1.34	3.31	147.01

**Significant differences at $p<.01$; correlated t-test.*

was in reverse order to the pre-session period with the exception that the near point determinations preceded the contrast sensitivity measurements.

At the conclusion of the week, a non-directive interview procedure was used to assess the subject's perception of the purpose of the study. This was followed by a full debriefing.

RESULTS

PERFORMANCE

Insofar as a majority of the data from this study has not been transferred to a main-frame computer, detailed data analyses have not yet been accomplished. However, certain preliminary findings have been determined by hand. Recall that the amount of incentive pay earned by each subject on each day was computed by determining the average increase in keystrokes per minute over baseline, and then subtracting a correction for the number of errors per minute. These incentive data are indicated for each subject in Table 1.

The percentages of improvement in incentive pay as a result of working under good ergonomic conditions ranges from slightly below zero to 81%, with a mean of 24.7%. The difference between the best and worst case is statistically significant ($t(12)=3.36$; $p<.01$). If, as seems reasonable, we can argue that these differences in incentive pay reflect differences in performance, it can be seen that ergonomic design appears to have a major impact on performance.

A closer examination of Table 1 reveals the likely presence of an asymmetric order effect resulting from the particular counterbalanced order used (ABBA vs. BAAB). Specifically, subjects 4,7,9,11,13 and 15, who started under the worst case conditions yielded a much higher best-worse difference in incentive pay (0.62 +/− .28) than did the remaining subjects who started under the best case condition (0.12 +/− .2). Values in parentheses represent mean best-worse differences plus or minus two standard errors of the mean.

QUESTIONNAIRE RESULTS

Questionnaire data for 12 of the 13 subjects were available for analysis. (Problems in coding required temporary discarding of the 13th subject; however, inspection of the data does not indicate any likely effect on the following conclusions.) Table 2 indicates the average differences between pre- and post-session responses for each questionnaire items by condition and day.

Inspection of the data in Table 2 indicates that the largest increases in complaints from beginning to end of session occurred for questions relating to pain in arms, neck, and lower back, and these items also showed the largest differences between best and worst case conditions. In the case of question 4 (pain in arms), the average response difference across days was 5.27 for the best case and 7.84 for the worst case; a 48.86% increase. Comparable figures for question 6 (neck, shoulder, and upper back) were 9.92, 13.58, 36.89%; and for question 8 (pain in lower back) were 9.69, 13.5, 39.31%.

A careful examination of the data indicates that the majority of the differences between best and worst cases seems to be accounted for by the first day's data. The results are significant for days 1 and 2 of question 6 ($t(12) = 3.57$; $p < .01$) and question 8 ($t(12) = 2.11$; $p < .01$). Comparable days 3 and 4 differences were not significant.

Thus, despite the small number of subjects relative to those typically employed in questionnaire administration, there are indications of differences in musculoskeletal complaints between best and worst case ergonomic conditions; at least on the first two days of the study.

At the same time, the visual complaints present a complex pattern of interactions which need to be investigated in further detail. One possibility, born out by subjective impressions, is that the visual testing procedures themselves were producing considerable amounts of eye strain. Since these were administered prior to the pretest questionnaire but after the post-test questionnaire, the consequences might have been larger visual complaints at the pretest; resulting in the negative difference scores seen in Table 2.

Examination of the responses to the concluding non-directive interview indicates a unanimous, sometimes emphatic, preference for best case over worst cas working conditions. Components of the workstations specifically mentioned as salient in this preference were chair (indicated by 69% of respondents), wrist rest (46%), working height (39%), and copy holder (31%). It is interesting that 5 of the 13 subjects found lighting and glare conditions uncomfortable in the worse case condition, but three others preferred the higher levels of illumination to be found therein.

DISCUSSION

Although these results are preliminary, they provide reasonably strong support for the efficacy of good ergonomic design of VDT workstations in reducing musculoskeletal complaints as well as increasing performance. Furthermore, the basic experimental design seems to be a useful approach to use in making analytic comparisons of the effectiveness of specific ergonomic components (e.g., adjustable vs. unadjustable furniture while lighting is optimized). At the same time, while it is recognized that the obtaining of an asymmetric order effect requires a replication of this study using different groups of subjects under each condition,[9] to assess the exact degree of performance increase, it must be pointed out that an analysis of just the first day's data—which, in effect, constitutes a small but unbiased between groups experiment, resulted in a mean increase which was statistically significant ($t = 2.20$; $p < .05$).

With regard to the relationship between visual complaints and glare, the results of this study are equivocal at best. Examination of questionnaire as well as interview data indicates that both the assessment procedure as well as the generation of glare conditions themselves need to be reexamined.

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