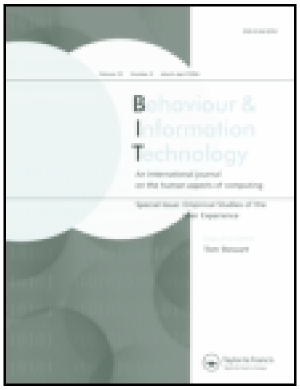

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Ergonomic predictors of visual system complaints in VDT data entry work

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Abstract. The relationship between ergonomic demands and visual system complaints was investigated among video-display-terminal (VDT) operators at two state agencies. Ergonomic factors suspected of posing visual demands were objectively assessed at 40 data-entry workstations. A questionnaire survey was also administered to gather information on somatic discomfort, demographic and personal characteristics, and extent of VDT use for operators at these workstations, and for several hundred additional operators in the two agencies. Regression analyses indicated that personal factors such as age and use of corrective eyewear accounted for relatively little of the variance in measures of visual system complaints. However, regression models that incorporated viewing distance and illumination measures accounted for 38%–49% of the variance in these measures. The present investigation is one of the few attempts to assess objectively an array of physical workplace factors and to examine, within a multivariate framework, their influence on visual system complaints.

1. Introduction

A large body of research indicates that visual system complaints (i.e. ocular discomfort and visual disturbances) are common in video-display-terminal (VDT) work. (See WHO 1987, for a review of this literature.) It is generally accepted that these problems are associated with adverse lighting conditions or display characteristics. However, empirical data linking working conditions to visual complaints are scarce (Berquist 1984, WHO 1987). Surprisingly, there have been few studies which have objectively assessed an array of physical workplace conditions and systematically examined their relationship with visual complaints in VDT work.

In an extensive evaluation of VDT work and health effects, the World Health Organization (1987) cited 12 field studies that examined the relationship between display or workroom characteristics and visual complaints. Seven of these studies were based on subjective ratings of physical workplace conditions. However, the use of subjective measurements for this purpose has been criticized (NRC 1983).

Only five of the 12 field studies cited in the WHO report used objective measures of workroom lighting or display characteristics. Laubli *et al.* (1980) reported that the magnitude of character luminance oscillation and luminance contrast of the display foreground/background were related to 'eye impairments'. Stammerjohn *et al.* (1981) confirmed operator reports of problems with glare through objective measurements of reflected VDT glare. Sauter *et al* (1983) found that 'visuo-ocular discomfort' was

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positively related to illumination levels at both the keyboard and the work surface area where a source document is normally positioned. Knave *et al.* (1985) observed that eye discomfort increased with a larger luminance ratio in the visual field (e.g. manuscript/screen). Padomos and Pot (1987) reported that eye discomfort was related to blurred characters on the VDT.

However, in all but one (i.e. Padomos and Pot 1987) of the five studies that employed objective assessment methods, the relationship of ergonomic conditions with visual complaints was examined by means of relatively simple correlational methods or other univariate techniques. Such an approach does not allow for determination of the relative influence or interaction of multiple ergonomic factors. It also fails to adjust for possible confounding factors such as age, eyewear use, and extent of daily VDT use.

In sum, there has been little attempt to develop or test, within a multivariable framework, explanatory models of visual complaints in VDT viewing based on objective assessment of working conditions.

In the present study, stepwise regression techniques were used to examine the relationship of visual system complaints in VDT data entry workers with ergonomic aspects of the workplace presumed to pose visual demands.[1] Relevant demographic and personal characteristics of VDT users and extent of daily VDT use were also introduced as predictors in order to control for their potential effects and to examine their importance in relation to physical workplace conditions. Data were gathered by means of a self-administered questionnaire survey of VDT users and an objective, ergonomic evaluation of physical workplace conditions. The study was conducted as part of a consultation by the National Institute for Occupational Safety and Health (NIOSH) to evaluate working conditions in two agencies of state government.

2. Methods

2.1. *Subjects*

Questionnaire surveys soliciting information on demographic, job, and health factors were returned from 905 of an estimated 992 VDT users in two state agencies (full population targeted for the NIOSH consultation). The predominant job title of survey respondents was data entry machine operator (68% of respondents). Eighty-seven per cent of the survey respondents were female.

A study sample of 40 data entry machine operators was drawn prior to survey administration for purposes of detailed ergonomic evaluations at their workstations. The sample was a subset of 539 female data entry machine operators who participated in the survey. Sample selection was conducted in a purposive fashion (Baily 1978) in order to represent variations in prevailing conditions with respect to lighting and related VDT/workstation design factors. All of the participants in the ergonomic sample had a tenure of employment of at least three months, and were permanent, full-time, data entry workers.

2.2. *Research measures*

Data were obtained through questionnaire survey and objective assessment of physical workplace conditions. The questionnaire survey was essentially equivalent in design to instruments used in previous NIOSH-sponsored research of VDT work (Smith *et al.* 1981, Sauter *et al.* 1983). Included in the survey were items relating to the work environment, workstation design, task demands, extent of daily VDT use, demographic and personal factors, and the frequency of experiencing various affective and somatic disturbances.

With respect to the objective assessment of physical workplace conditions, variables included reading distances and gaze angles, screen reflection measures, and measures of direct glare in the visual field. Gaze angles were measured using a goniometer and reading distances with a tape measure. A recently calibrated photometer (Litemate Spotmate, Burbank, CA) was used for luminance and illumination measurement.

2.2.1. *Predictor variables*

Survey measures. The survey was used to gather information on the following variables: AGE (1 = < 40 yrs, 0 = ⩾ 40 yrs), HOURS OF VDT USE (hours of VDT use per day: 1 = < 1 hour, 2 = 1–2 hours, 3 = 3–4 hours, 4 = 5–6 hours, 5 = 7–8 hours, 6 = 8 hours or more), and EYEWEAR (1 = wear glasses, 0 = does not wear glasses).

Ergonomic measures. Three categories of ergonomic variables were assessed: reading distances and gaze angles, workstation lighting, and screen reflections.

Measures of reading distances and gaze angles included:

- Eye-to-document distance (cm): DOCUMENT DISTANCE
- Eye-to-display distance (cm): DISPLAY DISTANCE
- Most comfortable reading distance[2] (cm): COMFORTABLE READING DISTANCE
- Far point of comfortable vision[2] (cm): FAR READING DISTANCE
- Near point of comfortable vision[2] (cm): NEAR READING DISTANCE
- Lateral separation of document and display (degrees and cm): LATERAL SEPARATION
- Vertical separation of document and display (degrees and cm): VERTICAL SEPARATION
- Frequency of gaze shift per minute between document and VDT: GAZE FREQUENCY

Measures of workstation lighting:

- Keyboard, document, and display-background luminance (candelas/m^2): KEYBOARD LUMINANCE, DOCUMENT LUMINANCE, and DISPLAY LUMINANCE
- Visual foreground luminance (average of luminances in candelas/m^2 30° left, 30° right, and directly behind the VDT): FOREGROUND LUMINANCE
- Illuminance at the display, keyboard, and desk-top illuminance (lux): DISPLAY ILLUMINANCE, KEYBOARD ILLUMINANCE, and DESK-TOP ILLUMINANCE
- Presence of a luminaire and/or window in the visual field (0 = luminaire, 1 = luminaire + window): GLARE SOURCE[3]
- Brightness of the luminaire or window (whichever is closest to line of sight) (candelas/m^2): GLARE LUMINANCE
- Visual angle to the luminaire or window (whichever is closest to line of sight): GLARE ANGLE

Measures of screen reflection included:

- Presence or absence of reflections from the screen (0 = yes, 1 = no): SCREEN REFLECTIONS[4]

- Proportion of the display affected by screen reflections (1 = 0%–25%, 2 = 26%–50%, 3 = 51%–75%, 4 = 76%–100%): REFLECTION PROPORTION[4]
- Degree of image visibility loss due to screen reflections (0 = none, 1 = low, 2 = medium, 3 = high): IMAGE VEIL[4]

2.2.2. *Outcome variables*

Visual discomfort was assessed using a ten-item checklist with the following response format: 1 = never, 2 = less than once a week, 3 = weekly, 4 = several times per week, 5 = daily.

Factor analyses (oblique rotation) were performed on the visual discomfort items using the entire survey sample with complete data for these items ($n = 792$). A two-factor solution accounted for 72% of the total variance.[5] One factor, corresponding to 'ocular' discomfort, consisted of five items: tearing/itching eyes, burning eyes, sore eyes, red eyes, and dry eyes. An ocular discomfort measure (OCULAR DISCOMFORT) was created by the simple, linear combination of these items. Cronbach's alpha (α) measure of internal consistency/reliability for this measure was 0·88.

The second factor, corresponding to 'perceptual' discomfort, consisted of two items: blurred vision and double vision. A perceptual discomfort measure (PERCEPTUAL DISCOMFORT) was created by the simple, linear combination of these two items ($\alpha = 0{\cdot}73$). The Pearson correlation of OCULAR DISCOMFORT and PERCEPTUAL DISCOMFORT was 0·62.

Descriptive statistics for the ergonomic factors, relevant user and task characteristics, and visual system complaints, are presented in table 1.

2.3. *Procedure*

Data collection. Administration of the questionnaire surveys was directed by the investigators. Survey forms were distributed, completed, and collected during normal working hours. Ergonomic evaluations were also conducted by the investigators during normal working hours. These evaluations were standardized in terms of the measurement procedure employed at the workstation and time of day at which each measure was collected.

Data analysis. Stepwise regression techniques were used to develop explanatory models of ocular and perceptual discomfort. For each of the two types of visual problems, three separate sets of regression analyses were conducted; one for each of the three categories of ergonomic predictors (i.e. reading distances and gaze angles, screen reflections, and workstation lighting). In addition to the simple terms, quadratic and cross-products terms were examined in the regression models. Also, other terms were created through the logical combination of the ergonomic variables. For example, a term was formed from the ratio of the most comfortable reading distance and the document reading distance variable (i.e. COMFORTABLE READING DISTANCE/DOCUMENT DISTANCE), since visual strain might be expected to increase as these two distances become more discrepant.

Variables were entered or removed from the models of visual discomfort using a stepwise procedure (University of California, BMDP2R 1981). BMDP criteria of 'F to enter' = 4 and 'F to remove' = 2·996 were used to govern the stepping process. In each of the regression analyses, simple terms were entered first, followed by the more complex terms.

Before analyses to examine the influence of the ergonomic variables were conducted, the effects of extent of daily VDT use (HOURS OF VDT USE) and

Table 1. Descriptive statistics for the research measures ($n = 40$).

	Mean	s.d.	Range
Viewing distance variables			
Document distance (cm)	54·44	6·32	42–67·5
Display distance (cm)	50·90	10·38	35·5–73
Comfortable reading distance (cm)	51·72	10·87	37·5–76·5
Near reading distance (cm)	28·99	11·19	12–54
Far reading distance (cm)	92·08	14·57	56–100
Lateral separation (cm)	19·65	15·47	0–45
Lateral separation (degrees)	30·32	33·23	0–154
Vertical separation (cm)	22·74	6·52	7–32
Vertical separation (degrees)	25·95	11·52	3–47
Gaze frequency (per minute)	29·95	10·44	14–51
Direct glare variables			
Keyboard lum (candles/m^2)	16·33	8·82	3·5–31·1
Display lum (candles/m^2)	7·68	15·12	2·1–93·4
Document lum (candles/m^2)	74·39	20·34	24·2–117·6
Foreground lum (candles/m^2)	53·69	25·98	14·9–153·3
Display illum (lux)	192·82	62·95	96·8–376·6
Keyboard illum (lux)	374·34	160·32	107·0–699·4
Desk-top illum (lux)	318·93	104·59	150·6–634·8
Glare lum (candles/m^2)	1730·00	350·39	1384–2076
Glare angle (degrees)	32·50	2·53	30–35
Glare source	Luminaire (95%)	Luminaire + Window (5%)	
Screen reflection variables			
Screen reflections	Yes (55%)		No (45%)
Reflection proportion	0%–25% (65%) 26%–50% (15%) 51%–75% (5%) 76%–100% (15%)		
Image veiling	None (45%) Low (40%) Medium (10%) High (5%)		
Task and user characteristics			
Hours of VDT use	4·8	0·44	4–6
Age	36·0	12·20	18–67
Eyewear	67·5% (yes)		32·5% (no)
Visual system complaints			
Ocular	2·05	0·85	1–5
Perceptual	1·60	0·79	1–4·5

individual characteristics (AGE and EYEWEAR) on visual complaints were assessed for the full group of female, data entry machine operators ($n = 489$), that had complete data on these measures.[6] Significant predictors were then incorporated into the regression analyses that assessed the influence of ergonomic variables among the sample of 40 data entry operators.

3. Results

Preliminary regression analyses that examined the influence of the AGE, EYEWEAR, and HOURS OF VDT USE variables showed effects of the AGE and EYEWEAR variables on both ocular and perceptual discomfort. However, in each case, the explained variance was very low (i.e. less than 5% in both models). Both ocular discomfort and perceptual discomfort were found to decrease with age and with the use (vs. non-use) of corrective eyewear. Since these two variables were predictive of the visual outcome measures, they were retained for inclusion in regression analyses that examined the predictive influence of the three categories of ergonomic variables.

3.1. *Reading distances and gaze angles*

Tables 2 and 3 present the results of the stepwise regression analyses that examined the influence of variables pertaining to reading distances and gaze angles. Equivalent models were returned for the prediction of ocular and perceptual discomfort, accounting for 49% and 38% of the total variance, respectively.[7]

Inspection of tables 2 and 3 indicates that after locking in the AGE and EYEWEAR variables that were significant in the preliminary analyses, two additional terms entered each model. The first term corresponds to near point of comfortable vision (NEAR

Table 2. Regression model for ocular discomfort as a function of ergonomic variables related to reading distances and gaze angles* ($n = 40$) (Model $R^2 = 0{\cdot}49$).

Variable	Standardized estimate	Partial correlation
Age	0·42	0·30
Eyewear	−0·12	−0·10
Age × Eyewear	0·26	0·17
Near reading distance − *M*	0·37	0·43
Document distance − *M*) × ([comfortable reading distance/document distance] − *M*)	−0·39	−0·45

* 'F To Enter = 4' and 'F To Remove = 2·996'

Table 3. Regression model for perceptual discomfort as a function of ergonomic variables related to reading distances and gaze angles* ($n = 40$) (Model $R^2 = 0{\cdot}38$).

Variable	Standardized estimate	Partial correlation
Age	0·44	0·29
Eyewear	−0·07	−0·06
Age × Eyewear	−0·09	−0·05
Near reading distance − *M*	0·37	0·36
(Document distance − *M*) × ([comfortable reading distance/document distance] − *M*)	−0·54	−0·53

* 'F To Enter = 4' and 'F To Remove = 2·996'.

READING DISTANCE), and indicates that recession of the near point is associated with an increase in ocular and perceptual discomfort. The second expression entering the models was more complex, involving the most comfortable reading distance (to the display) (COMFORTABLE READING DISTANCE), and the document reading distance (DOCUMENT DISTANCE). The effect of this second expression on ocular discomfort is illustrated in figure 1. The darker area of the surface in figure 1 covers all of the actual data points for the combination of the most comfortable reading distance and the document distance variables, while the lighter area represents an extrapolation throughout the full range of values for these variables. As seen in figure 1, ocular discomfort is least when the document distance is approximately the same as the comfortable reading distance, and increases as the discrepancy between the two distances increases, particularly with a closely positioned document in combination with a comfortable reading distance that is faraway. A similar effect was noted in the perceptual discomfort model.

The main effects of AGE and EYEWEAR in both models were consistent with observations in the larger sample of data entry operators. There was also a fairly strong interaction of these two variables in the prediction of ocular discomfort. Older workers (i.e. age$\geq$40) with glasses reported much less discomfort than did older workers without glasses. However, this relationship did not hold for younger workers (i.e. age$<$40). In the model for predicting perceptual discomfort (table 3), the interaction was of just the opposite form, but its contribution to the model was negligible, as was the main effect of the EYEWEAR variable.

3.2. *Screen reflections and workstation lighting*

Using the original stepping criteria (i.e. 'F to enter' = 4 and 'F to remove' = 2·996), the regression analyses failed to return a model containing any of the variables related to screen reflections for either ocular or perceptual discomfort. Similarly, none of the variables related to workstation lighting were influential in the prediction of either discomfort measure.

These results were unexpected and inconsistent with conventional wisdom. It is possible that, for purposes of predicting discomfort, assessment of screen reflections and problematic lighting by the investigators may be less appropriate than the VDT users' self-reports. To examine this premise, VDT users' responses to the questionnaire item 'glare at the workstation' was used to predict visual discomfort. This item was

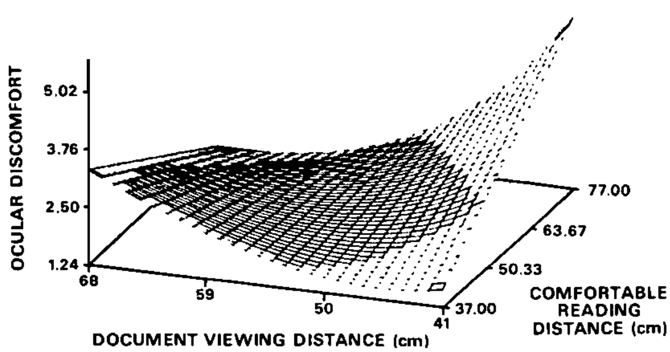

Figure 1. Surface of fitted ocular discomfort values as a function of comfortable reading distance and document distance.

found to explain 14% of the variance in the ocular discomfort scale and 10% in the perceptual discomfort scale. In both cases, glare was associated with increased strain.

For further exploratory purposes, the original stepping criteria ('F to enter = 4' and 'F, to remove = 2·996') were relaxed to 'F to enter = 2' and 'F to remove = 1·996'. This procedure had no impact in the prediction of perceptual discomfort. However, for ocular discomfort, a model accounting for 45% of the variance was generated (table 4). Inspection of table 4 indicates that AGE and EYEWEAR effects, as well as their interactions, were the same as in the prediction of ocular discomfort from measures of reading distances and gaze angles. Regarding the GLARE SOURCE variable (i.e. overhead luminaire or luminaire + windows in the visual field), it was found that discomfort increased for VDT users with a window in the visual foreground (although only a few VDT users were so affected).

As can be seen in table 4, the KEYBOARD ILLUMINATION and DISPLAY ILLUMINATION variables also played an influential role, but the effect was complex and not readily interpretable. The effect of the expressions involving the KEYBOARD ILLUMINATION and DISPLAY ILLUMINATION variables is illustrated in figure 2. The dark and light areas of figure 2 can be interpreted (with respect to actual and extrapolated discomfort values) in the same manner as in figure 1. As shown in figure 2, at keyboard illumination levels above the mean, increases in screen illumination were associated with greater discomfort. However, the reverse was true at keyboard illumination levels below average.

This effect suggests that when keyboard illumination is low (possibly indicating insufficient workstation illumination), increasing illumination at the display might be associated with improved lighting for visual tasks and, hence, reduced discomfort. On the other hand, increasing screen illumination at other than low levels of keyboard illumination may create the potential for discomfort or disability glare and, thus, visual discomfort. However, caution is urged in the interpretation of the effect illustrated in figure 2 and other effects suggested by the regression model, since relaxed stepping criteria were used to generate this model.

4. Discussion and conclusions

Perhaps the most noteworthy finding of this investigation in the suggested effect of ergonomic factors on visual accommodation mechanisms in explaining visual strain. The results indicate that discrepancies in the distance of visual targets from the most comfortable reading distance should be minimized in VDT work so as to reduce

Table 4. Regression model for ocular discomfort as a function of ergonomic variables related to workstation lighting* ($n = 40$) (Model $R^2 = 0·45$).

Variable	Standardized estimate	Partial correlation
Age	0·24	0·18
Eyewear	−0·12	−0·10
Age × Eyewear	0·49	0·30
Glare source	0·35	0·40
(Keyboard illumination − M)^2	−0·76	−0·43
(Keyboard illumination − M) × (display illumination − M)	0·62	0·37

'F to enter = 2' and 'F to remove = 1·996'.

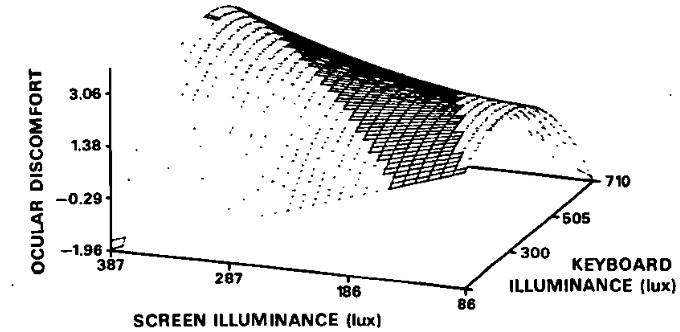

Figure 2. Surface of fitted ocular discomfort values as a function of screen and keyboard illuminance.

accommodative range, particularly close focus capability, also reduces the potential for strain. Such observations underscore the importance of careful attention to placement of visual source material in VDT work, and appropriate visual correction for VDT users.

The fact that glare of lighting factors, as assessed in the ergonomic evaluation, generally failed to have any apparent influence on visual system strain does not necessarily diminish the importance of these variables. Results suggest that VDT users' perceptions of certain, potentially stressful, lighting conditions (e.g. glare) may be more sensitive or valid than measures based upon efforts to quantify these lighting conditions in a more objective manner. Alternatively, it should be noted that the amount of variance in some of these measures was limited (e.g. REFLECTION PROPORTION, IMAGE VEILING), and in other cases the mean scores were near recommended levels (see table 1). As an example of the latter, the mean illuminance of the desk-top was 105 lux. These circumstances may have contributed to the lack of statistical association of some of the ergonomic variables with visual discomfort.

With respect to VDT-user characteristics, the reduction in visual strain among older workers is consistent with prior research findings (e.g. Sauter *et al.* 1983). This effect may be due to a self-selection or 'healthy worker' effect. That is, VDT users who are unable to adjust to the increased visual stresses of the ageing process find other jobs. Although such an explanation is plausible, this phenomenon deserves further analysis. The eyewear effect, on the other hand, is at variance with the findings of other investigations (e.g. Cakir *et al.* 1978, Sauter *et al.* 1983) that have shown VDT users with corrective eyewear to be at a disadvantage. Both investigators have suggested that in certain cases (e.g. use of reading glasses) conventional eyewear may be inappropriate for VDT viewing. Regarding the age and contrary eyewear effects, however, it must be remembered that collectively they accounted for only a very small fraction of the explained variance in the models of visual discomfort.

In summary, the contribution of ergonomic factors to visual strain in VDT work is widely recognized (WHO 1987). However, there has been little empirical research to validate the probable factors involved, to define the interplay among these factors, and to rank their relative importance. The intent of the present investigation was not to question the role of ergonomic conditions in influencing visual discomfort in VDT use, but rather to extend our understanding of these factors within a multivariate framework.

Acknowledgment

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Notes

1. Since there is no established relationship between changes in visual function and subjective visual complaints, optometric measures were not employed in this investigation (WHO 1987).
2. Determined using the video display as a visual target.
3. All subjects had either an overhead fixture and/or window in the visual field.
4. Determined by concurrence of two of three investigators viewing the display from the perspective of the seated operator.
5. Only factors with eigenvalues in excess of 1·0 were retained. The entire sample was used to define dimensions of visual discomfort in the most reliable manner.
6. Since the data for the AGE, EYEWEAR, and HOURS OF VDT USE variables were available for the entire group of female, data entry operators, this full group was utilized to obtain the most reliable estimate of the effects of these variables.
7. Note, in tables 2 and 3, that the terms for ergonomic variables are 'centred', meaning that the individual values for each of the variables are deviations from their sample means.

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