

The Effect of an Ergonomic Intervention on Musculoskeletal, Psychosocial and Visual Strain of VDT Data Entry Work: The United States Part of the International Study

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The United States MEPS (musculoskeletal—eyestrain—psychosocial—stress) study consisted of 1 group of 28 female data entry operators. The intervention was in 3 parts: workstation redesign (including advanced ergonomic chairs, motorized adjustable workstations, advanced adjustable keyboards, adjustable copyholders, adjustable footrests, monitor support surfaces) and ergonomic training/coaching and corrective lenses. After the intervention, statistically significant reductions in physical signs (trigger points, neck and shoulder mobility), subjective reports of intensity and frequency of musculoskeletal pain, and subjective reports of visual problems were observed. Static load during the work sample, as assessed by experts, improved after the intervention as did measured postural angles of head and trunk and subjective assessment of users of ergonomic characteristics of the workplaces. For all of these measures, improvements observed 1 month after intervention were also observed in the 1-year follow-up. Trapezius load, as assessed by electromyography (EMG), decreased after intervention, but then increased in the follow-up. The increase was interpreted as a calibration problem.

ergonomic intervention VDTs office ergonomics musculoskeletal disorders visual strain

1. INTRODUCTION

This paper describes the results of the United States part of the international MEPS (musculoskeletal—eyestrain—psychosocial—stress) project. National teams in Norway, the USA and Poland conducted the project.

The aim of the study was to evaluate short- and long-term effects of an ergonomic intervention on the musculoskeletal, visual and psychosocial

strain of a group of female visual display terminal (VDT) data entry workers. Studies were performed according to the MEPS protocol [1] described in the lead article in this issue of the *International Journal of Occupational Safety and Ergonomics (JOSE)*. The evaluation of the musculoskeletal, visual and psychosocial factors was performed before intervention, 1 month after and 1 year after the ergonomic interventions.

2. METHODS

The methods are described in Dainoff et al., in this issue of *JOSE* [2].

2.1. Subjects

The study was conducted at the Cincinnati Service Center (CSC) of the U.S. Internal Revenue Service (IRS). Participants in the study initially included 29 female data entry employees selected from volunteers. Twenty-six employees remained in the study through its completion, and it is these subjects whose data were analyzed. All participants were permanent employees of CSC working in Data Conversion. Their average age was 41.02 with a standard deviation of 9.58. The mean number of years working at IRS was 15.71 with a standard deviation of 6.55. Nine described themselves as married/cohabiting with children at home, 5 were married/cohabiting with no children at home. Ten of the participants described themselves as not living with another adult; of these 8 had children at home.

3. ERGONOMIC INTERVENTION

3.1. Corrective Lenses

An optometric examination of each participant was conducted as part of the pre-intervention Data Collection Phase. This examination specifically considered the visual function of the participant with respect to the particular visual demands of the workplace. When needed, appropriate corrective lenses were prescribed according to specific optometric criteria as laid out in the MEPS protocol.

3.2. Workstation Redesign

A complete redesign of each workstation was carried out so as to provide an optimum ergonomic workplace. The redesign included the following components:

1. Ergonomic chairs all had independent height, seat pan angle, and backrest angle adjustments. In addition, seat pan and backrest could be

put into dynamic movement. The seat height adjustment range was from 16 to 20.5 in. (40.64 to 52.07 cm). The backrest was height adjustable over a range of 3 in. (7.62 cm), and the backrest height was at least 14 in. (35.56 cm). Seat pan angle inclinations included a range of from 5° forward to 5° backward. The backrest inclined 11° from vertical. All chairs had adjustable armrests, waterfall fronts, and five-prong bases.

2. Motorized adjustable worksurfaces were provided which allowed operators push button control of the worksurface height from a sitting to a standing posture. Two sets of worksurfaces were provided: those ranging from 25 to 41.9 in. (63.5–106.43 cm), and those ranging from 26 to 43.9 in. (66.04–111.51 cm). The latter were assigned to the taller employees. Horizontal dimensions were 60 in. wide by 40 in. (152.4 by 101.6 cm) deep.
3. The keyboards employed were fully adjustable. Each keyboard was divided into three movable sections: the section usually keyed by the left hand, the section usually keyed by the right hand, and the numeric keypad. Each section of the keyboard could lift, tilt, swivel, and be moved right or left along the base, and be locked in position after adjustment. It was possible to interchange sections so that the numeric keypad could be placed in the center.

The keyboard followed the IBM/AT QWERTY layout, and met or surpassed ANSI (American National Standards Institute) standards with respect to key travel, force, tactile feel, and key spacing. Because the IBM/AT layout differs from that of the original proprietary keyboards located at the site, an exact match of key locations and positions was not possible. Therefore, alternative mapping layouts of the adjustable keyboard were developed iteratively over a period of 2 months in cooperation with the manufacturer. Employees participated in the mapping process.

4. Customized copyholders were specially designed for the study to meet the following requirements: accommodate a stack of documents 3 in. (7.62 cm) thick; provide a transparent spring-loaded clip to facilitate

working through documents without cutting off the view of codes underneath; adjustable in viewing height and angle.

5. Custom-made monitor supports were provided for each person. These were based on measurements of each participant's preferred monitor viewing height. These measurements were made after the participants had received training regarding the necessity to position the monitor at a comfortable height and angle while maintaining the hands and forearms in efficient postures by adjusting the worksurface height. The supports were also angled to increase the tilt range of the monitors in order to minimize glare.
6. Adjustable footstools were provided to all participants. The footstools could be adjusted through an 8-in. (20.32-cm) range in 1-in. (2.54-cm) increments.

3.3. Training

A customized ergonomic training program was designed to empower each participant to take full advantage of the flexibility provided by the ergonomic intervention. This training incorporated a general knowledge of ergonomic principles along with specific instruction relating to the particular pieces of ergonomic equipment (e.g., chairs, workstations, keyboards). Thus, the participants were provided with knowledge of "why" a given working posture might be more comfortable and efficient, along with "how" ergonomic equipment might be adjusted to achieve such postures. The training plan was divided into the phases indicated in the following sections.

3.3.1. Phase 1—classroom training

A classroom workshop introduced participants to the principles of ergonomics, with emphasis on human physiology as the rationale for making ergonomic recommendations. This emphasis on principles was important in that it educated the participants in ergonomics they could use both on and off the job—all of which impacts the worker's ability to function well at work.

3.3.2. Phase 2—on-site coaching

Once workstation equipment was installed, individual instruction/coaching at the worksite was conducted until participants were familiar with all equipment and able to use it as required.

3.3.3. Phase 3—follow-up visits No. 1

Throughout the intervention period, follow-up coaching visits at the workstations were made from time to time, as convenient with the CSC staff.

3.3.4. Phase 4—follow-up visits No. 2

Following the first post-intervention data collection, additional follow-up visits were scheduled in cooperation with the CSC staff. These visits were carried out throughout the remainder of the contract period until the tax season; they included a Progress Report questionnaire, some measurements of the adjustments being made by the participant, and coaching in achieving ergonomic health and comfort. Ergonomic thinking was further encouraged by the MEPS Newsletter, which was distributed periodically to all participants.

4. RESULTS

4.1. Rationale and Strategy

The framework for the statistical analysis as initially set forth in the international MEPS trial plan, was that of an overall set of analyses conducted on the combined international data, with individual national analyses to be presented as a subset of the international results. A major strategic concern in approaching the analysis was that of the large number of measured variables (approximately 435). The initial method proposed in the MEPS protocol of reducing and compressing the original data set was through principal components analysis on the entire international data. However, a number of operational problems prevented some of the national studies from being completed. As a result, the size of the international data base

was too small to allow the principal components approach to be feasible.

Accordingly, for the U.S. component of the study, a different strategy was developed. We call this the critical question approach. Within each of the groups of measures described earlier, we have identified a small number of individual variables or combinations of variables that would seem to bear most directly on the question of whether or not the intervention was effective. We then present univariate tests on these critical variables across the time periods corresponding to the point

number of trigger points from Commencement to the 30-Day Post-Test. The difference between the 30-Day Post-Test and 1-Year Post-Test was not statistically significant. For the overall F test, $F_r = 198.69$, $p < .001$ for 26 subjects and 3 conditions. The total number of observed trigger points for each observation period can be found on the first line of Table 1. The modal numbers of trigger points are in adjacent parentheses. It can be seen that the modal number of trigger points was 6 at Commencement, but dropped to 0 after the intervention.

TABLE 1. Number of Positive Signs in Physical Exam (Modes or Percentages in Parentheses)

Physical Exam	Commencement	30-Day Post-Test	1-Year Post-Test
Trigger points	128 (6)	34 (0)	17 (0)
Shoulder tests	23 (22.12%)	12 (11.54%)	7 (6.73%)
Neck mobility	19 (24.36%)	4 (5.13%)	1 (1.28%)

at which measurements were taken. The null hypothesis is that there is no difference across the three time periods; the alternative hypothesis that there is an improvement immediately following the intervention and that this improvement is maintained for a period of 1 year. These hypotheses are evaluated using, as appropriate, one-way repeated measures analysis of variance, Friedman two-way analysis of variance by ranks, and chi square to test the overall main effects; and Tukey HSD and its Friedman equivalent, for comparisons across means. It should be emphasized that the critical variables were selected prior to examination of the data.

4.2. Results of the Physical Examination

Three critical items from the physical examination were selected for analysis. Each reflects an objective determination of specific signs or precursors of musculoskeletal disorder. Further, it should be emphasized that, on the two post-intervention examinations, the examining physician was not aware of the previous findings on the physical examination for each participant.

The first of these measures was a determination of the number of painful pressure or trigger points. Results, utilizing the Friedman test, indicated that there was a statistically significant decrease in the

The second measure from the physical examination represents a combination of elements from the clinical examination of the shoulder joint: isometric and endurance test, palpation with and without resistance, and mobility in the joint. The overall variable consists of the number of positive signs across all of the tests, where a positive sign indicates the presence of a potential musculoskeletal problem. The results indicate a significant decrease in frequency of positive signs following the intervention; chi square ($2 df$) = 817.5, $p < .001$. Table 1, line 2, contains the number of positive signs for each observation period. Percentages of positive signs seen among all participants within each observation period are in adjacent parentheses.

The third measure from the physical examination also represents a combination score resulting from the clinical examination of neck mobility. This score consists of the number of participants who experienced pain during manipulation of the neck in flexion, extension, sideways flexion, or rotation. The results indicate a significant decrease in pain following the intervention; chi square ($2 df$) = 429.4, $p < .001$. Table 1, line 3, contains the number of pain reports for each observation period. Percentages of positive signs seen among all participants within each observation period are in adjacent parentheses.

Thus, the results from the physical examination, with relatively objective measures, indicate a clear decrease in indicators of musculoskeletal disorder following the ergonomic intervention—a decrease which persisted over the period of 1 year.

4.3. Musculoskeletal Pain—Subjective Ratings

Combination measures were derived by averaging critical variables selected for analysis from the participants’ subjective ratings of musculoskeletal pain or discomfort. The critical variables were intensity of pain, and frequency of pain. These ratings were obtained from questionnaires filled out by participants. For each of the critical variables analyzed, reports of pain or discomfort in the neck, shoulder, forearm/hand, back, and legs were combined in a single measure.

The first combination measure consisted of participants’ reports of the average intensity of pain experienced during the past 6 months. Intensity was indicated on a Visual Analog Scale (VAS) ranging from 0 to 100. This scale

$F(2, 50) = 12.96, p < .001$. Table 2 indicates mean combined VAS scores with 95% confidence intervals in parentheses. In Table 2, for example, the mean VAS rating for intensity of pain at Commencement was 36.15 out of a possible score of 100. The 95% confidence limit was ± 5.27 around the mean, ranging from 41.42 to 30.88.

The second combination measure consisted of participants’ report of the average frequency of pain experienced during the past 6 months. Frequency was indicated on a 6-point category scale ranging from *never* to *daily*. On this scale, the larger the number, the greater the degree of reported pain or discomfort. Results, utilizing analysis of variance, indicated that there was a statistically significant decrease in the average frequency of pain/discomfort from Commencement to the 30-Day Post-Test. Use of the Tukey HSD test indicated that the difference between the 30-Day Post-Test and 1-Year Post-Test was not statistically significant. For the overall test, $F(2, 50) = 22.43, p < .001$. Table 2 indicates mean combined scores with 95% confidence intervals in parentheses.

TABLE 2. Musculoskeletal Pain—Means and Confidence Intervals Combined Values—6 Months

Musculoskeletal Pain	Commencement	30-Day Post-Test	1-Year Post-Test
Intensity	36.15 (5.27)	25.36 (5.21)	27.46 (5.23)
Frequency	1.55 (0.32)	0.97 (0.21)	0.92 (0.21)

consists of a horizontal line of standard length (100 mm). The attribute being measured, in this case pain, is labeled at points along the scale, and the respondent places a mark indicating the extent of pain. The distance of the mark, in millimeters, from the left of the scale is a measure of the response. On this scale, the larger the number, the greater the degree of reported pain or discomfort. For all VAS measures in this study, the maximum score is 100; the minimum is 0.

Results, utilizing analysis of variance, indicated that there was a statistically significant decrease in the average pain/discomfort intensity from Commencement to the 30-Day Post-Test. Use of the Tukey HSD test indicated that the difference between the 30-Day Post-Test and 1-Year Post-Test was not statistically significant, indicating long-term decrease in pain. For the overall test,

Thus, the results from the participants’ subjective reports indicate a clear decrease in musculoskeletal pain or discomfort following the ergonomic intervention—a decrease which persisted over the period of 1 year.

4.4. Static Load Assessment

During the work samples, ergonomic evaluations were carried out in parallel with the electromyographic and postural angle measurement. One component of this evaluation was an expert assessment by the ergonomist of the extent to which each participant’s working posture was likely to result in high static loads. This assessment was made after direct observation of the participant during the 45-min period of the work sample, using a standardized checklist. Six

separate postural components were evaluated: wrist angle, forearm angle, head/neck angle, trunk angle, support for lumbar spine, and stereotyped movement. The maximum possible score—indicative of high static load—for each participant was 6 points. A score of 0 indicated absence of static load. Results, utilizing the Friedman test, indicated that there was a statistically significant decrease in the static load scores from Commencement to the 30-Day Post-Test. The difference between

the overall test for trunk angle, $F(2, 50) = 12.22$, $p < .001$. On the other hand, the results are opposite to expectation for shoulder flexion. In this case, there was a statistically significant increase in average flexion angle from Commencement to the 30-Day Post-Test, but no difference between the 30-Day Post-Test and 1-Year Post-Test. For the overall test for shoulder angle, $F(2, 50) = 10.68$, $p < .001$. Table 3 indicates mean postural angles with 95% confidence intervals in parentheses.

TABLE 3. Postural Angles—Means and Confidence Intervals (Degrees of Flexion Angle)

Postural Angles	Commencement	30-Day Post-Test	1-Year Post-Test
Head	19.65 (1.49)	13.52 (3.10)	12.23 (3.58)
Shoulder	5.58 (4.06)	13.5 (3.29)	10.11 (3.56)
Trunk	8.00 (1.72)	3.62 (2.13)	2.15 (1.90)

the 30-Day Post-Test and 1-Year Post-Test was not statistically significant. For the overall F test, $F_r = 25.01$, $p < .001$. The modal static load score was 3 for Commencement, 2 for 30-Day Post-Test, and 0 for 1-Year Post-Test.

Thus, the results from the ergonomist's professional evaluation indicate a clear decrease in indicators of musculoskeletal static load following the ergonomic intervention—a decrease which persisted over the period of 1 year.

4.5. Postural Angles

During the work samples, angle sensors were used in conjunction with the physiometer to determine head, arm, and trunk posture. One indication of the effectiveness of the ergonomic intervention (furniture plus training) might be an improvement in participants' working posture as reflected in a decrease in flexion angle (forward bending). Therefore, mean flexion angle (in degrees) for head, shoulder, and trunk, over the period of the work sample, comprised three critical variables.

Results, utilizing analysis of variance, indicated that there was a statistically significant decrease in the average flexion angle for head and trunk from Commencement to the 30-Day Post-Test. Use of the Tukey HSD test indicated that the differences between the 30-Day Post-Test and 1-Year Post-Test were not statistically significant. For the overall test for head angle, $F(2, 50) = 12.85$, $p < .001$. For

The results from the postural angle measures indicate a clear decrease in head and trunk flexion, indicating an improvement in working posture following the ergonomic intervention, an improvement which persisted over the period of 1 year. In the case of increased shoulder flexion, the results of the previous analysis of static load, coupled with more informal observations, lead us to the conclusion that the increase in shoulder flexion was a positive adaptation to the new configuration of the adjustable keyboard.

4.6. Visual Problems

As part of the optometric examination, participants were asked to indicate whether they had, within the past 6 months, experienced any of four types of visual problems: fatigue, burning/itching, red eyes, or double/hazy vision. Results indicated that the number of people reporting each of those visual problems decreased following the intervention. Chi square values ($2 df$) and associated probabilities for each problem are as follows: fatigue = 14.0 ($p < .001$); burning = 22.0 ($p < .001$); redness = 17.0 ($p < .001$); hazy vision = 7.35 ($p < .05$). Table 4 indicates numbers of people reporting each visual problem. Percentages are in parentheses.

Thus, the results from the visual examination indicate a clear decrease in reports of visual problems following the ergonomic intervention—a decrease that persisted over the period of 1 year.

TABLE 4. Frequency of Visual Problems (Number and Percentage of People Reporting)

Visual Problems	Commencement	30-Day Post-Test	1-Year Post-Test
Fatigue	11 (42.3)	3 (11.5)	1 (3.8)
Burning/itching	16 (61.5)	5 (19.2)	0 (0)
Redness	11 (42.3)	3 (11.5)	0 (0)
Hazy/double vision	13 (50.0)	7 (26.9)	3 (11.5)

4.7. Ergonomic Evaluation—Subjective Assessment

Participants were asked for their subjective evaluations of various ergonomic attributes of their workplace. Two of these attributes, chair comfort and height adjustability of the keyboard support surface, were selected as critical variables. Each attribute was evaluated using a VAS ranging from 0 to 100, where a larger number indicates a more positive evaluation. Results, utilizing analysis of variance, indicated that there was a statistically significant increase in the positive evaluations of both chair comfort and keyboard height adjustability from Commencement to the 30-Day Post-Test. Use of the Tukey HSD test indicated that the differences between the 30-Day Post-Test and 1-Year Post-Test were not statistically significant. For the overall test for chair comfort, $F(2, 50) = 50.76, p < .001$. It was not necessary to carry out a similar test for keyboard adjustability, since the pre-post intervention distributions did not overlap. Table 5 indicates mean combined VAS scores with 95% confidence intervals in parentheses.

TABLE 5. Participants’ Ergonomic Evaluations—VAS Values—Means and Confidence Intervals

Ergonomics	Commencement	30-Day Post-Test	1-Year Post-Test
Seated comfort	42.50 (7.34)	75.65 (5.20)	75.77 (6.28)
Keyboard hight adjustability	5.50 (5.45)	83.80 (4.00)	85.27 (3.51)

Notes. VAS—Visual Analog Scale.

Thus, the results from the participants’ ergonomic evaluations indicate a clear increase in their impressions of chair comfort and keyboard surface height adjustability following the ergonomic intervention—an increase that persisted over the period of 1 year.

TABLE 6. Electromyographic Measures—Trapezius Muscle (Means and Confidence Intervals)

Trapezius Muscle	Commencement	30-Day Post-Test	1-Year Post-Test
No. shifts < 1%MVC	19.67 (12.5)	29.71 (19.4)	4.11 (5.4)
Proportion < 1%MVC	3.02 (2.07)	6.83 (6.04)	1.28 (1.38)

Notes. MVC—Maximum Voluntary Contraction.

4.8. Electromyography

During the work samples, electromyographic (EMG) recordings of right and left trapezius muscle were obtained, but only the records for the preferred arm were selected for analysis. Since muscle activity should be indicative of static postural load during data entry work, the critical variable to be examined relates to the extent to which muscle activity falls below a specified minimum level: 1% Maximum Voluntary Contraction (MVC). Two alternative measures of this variable were selected: the number of times EMG load dropped below 1%MVC (number of shifts), and the proportion of the cumulative distribution of EMG activity falling below 1%MVC [3].

Examination of the EMG records indicated that a number of subjects seemed to have difficulty with the biofeedback/tracking portion of the calibration. Accordingly, only 9 of the 26 participants had recordings which were acceptable across all three measurement sessions. Analysis of variance results from these 9 subjects indicates that, for both variables, the null hypotheses of no differences

across measurement sessions cannot be rejected. For the overall test for shifts, $F(2, 16) = 3.37, p = .06$. For the overall test for proportion, $F(2, 16) = 2.60, p = .10$. The mean number of shifts and proportions below 1% MVC are indicated in Table 6; 95% confidence intervals are in parentheses.

Examination of these results indicates two points of interest. First, the F test for the number of shifts was quite close to statistical significance at the .05 level. It is reasonable that, had we not had to discard so many subjects, the corresponding increase in power would have allowed us to achieve statistical significance. Thus, if we now examine only the comparison between Commencement and the 30-Day Post-Test, and correct for loss of power, there is at least a suggestion that muscle load decreased as expected following the intervention. However, the 1-Year Post-Test results are quite problematic. For both variables, these values are lower than at Commencement, presumably indicating a higher level of muscle load. Since these findings are in conflict with the consistent pattern of results observed thus far, a closer look at the 1 Year records was carried out.

It was determined that baseline resting levels during the 1-Year Post-Test were excessively high compared with previous levels. Since this resting level enters into the calibration equations, the effect would have been to artifactually lower both of our critical variables. Recall that resting levels were taken immediately after the participant was connected to the electrode leads. These high levels—specific to the 1-Year Post-Test—were obtained despite the use of relaxation techniques. We have identified two possible causes for these excessive high levels. The first may have reflected differences in the circumstances under which measurements were taken rather than actual differences in EMG levels among participants during the two post-intervention periods. There were two differences in procedure between the 30-Day and 1-Year Post-Tests. The first was that a different laptop computer was used because of a malfunction of the original laptop; the second was that a different room was utilized for the calibration. We cannot rule out equipment differences as an explanation since we have been informed by the manufacturer of the physiometer that if an electromagnetic field from some nearby equipment were present during calibration, this might have affected the results.

A second possibility is that, despite the aforementioned situational differences, the elevated resting levels were, in fact, accurate.

If so, the consistency of these high levels across participants might be explained by some organization-wide increase in stress levels. Addressing this possibility formed part of the rationale in selection of critical psychosocial variables to be examined in the following section.

The procedure for electrode placement, and, in particular, assessing the effectiveness of skin preparation through measurement of electrical resistance prior to calibration, was carefully followed and documented in all three measurement sessions. Records indicate no differences among sessions in placement and resistance.

A reanalysis of the raw data by A. Aarås and G. Horgen indicated a significant reduction in the static ($p = .03$) and median ($p = .008$) values comparing 30-Day Post-Test versus Commencement, while a significant increase was observed for 1-Year Post-Test versus Commencement ($p = .008$). This analysis supports the initial findings described earlier.

4.9. Psychosocial Measures

The MEPS protocol contained a large number of psychosocial questions to which participants were asked to respond. We have selected seven independent items, whose pattern of responses might bear on two different issues. The first issue, which is broadly conceptual, relates to any potential effect of the ergonomic intervention on the broader psychosocial context of the participants' workplace and home environments. The second issue, which is more narrowly focused, is concerned with identifying possible factors which might have resulted in the elevation of baseline EMG measures discussed in the previous section.

Each of the psychosocial variables was evaluated using a VAS score ranging from 0 to 100. "Job satisfaction" represents the response to the question: For how much of your working day can you say that you feel genuinely satisfied with your job? A VAS score of 100 represents *always*; 0 represents *never*. The next two questions ask the participant to compare other work tasks relative to VDT work. "Physical—other" reflects a comparison with respect to physical demand; "stress—other" reflects a comparison with respect

to stress. Both items are reverse coded so that VAS scores of 100 indicate that the non-VDT work is less physically demanding and less stressful. VAS scores of 50 indicate that both kinds of tasks are about the same.

“Unscheduled breaks” represents the response to the question: Can you decide when you want to take short unscheduled breaks for a few minutes? A VAS score of 100 represents *always*. “Opportunity to learn” represents the response to the question: To what extent do your work tasks involve the opportunity to learn something new? A VAS score of 100 represents *very much*. “Job security” represents the response to the question: How is the security in your present employment? This scale is reverse coded in that a VAS score of 100 reflects *Low—reason to fear release*. “Income” represents the response to the question: How do you regard your income? A VAS score of 100 represents *very good*.

Analysis of variance results indicated that none of the seven psychosocial variables approached statistical significance at .05 levels. Mean VAS scores are indicated in Table 7; 95% confidence intervals are in parentheses. *F* values (2 and 50 *df*) and associated probability values are as follows: Satisfaction = 0.26, *p* = .77, Physical = 1.41, *p* = .25; Stress = 0.95, *p* = .39; Breaks = 2.11, *p* = .13; Learn = 0.78, *p* = .46; Security = 1.76, *p* = .18, Income = 2.27, *p* = .11.

It does not appear that these psychosocial items are very helpful in addressing either of the two questions posed earlier. The most global measure, “job satisfaction”, is virtually constant across all three measurement periods. There are only two items which even approach statistical significance. Both seem to indicate a positive environment (increases in income and ability to

take unscheduled breaks). Neither is obviously related to the ergonomic intervention. Thus, there is no pattern of psychosocial results which reflects either an apparent effect of ergonomic intervention or a specific organizational stressor which might explain the inflated EMG resting levels.

4.10. Follow-Up

The physical and psychosocial environment of this study is a large, routinized, impersonal factory-like open office with constant pressure for throughput. This setting does not easily promote individualization or worker recognition. Rather, employees feel more like a nondescript part of a large mechanized body. Therefore, participating in the ergonomic intervention study differed dramatically from their normal routine.

Participants’ perceptions of their visual and musculoskeletal health were measured repeatedly, conversations with the principal researchers were frequent, plus they were able to participate in the design of equipment (e.g., desks, copyholders) to fit their own needs that differed from their co-workers, etc. To clarify that the significant positive results documented in this study were due primarily to the ergonomic interventions and not unduly influenced by the oft mentioned Hawthorne Effect, a follow-up study was carefully planned.

Individual brief exit interviews with each participant concluded with the interviewer’s appreciation for the interviewee’s participation and farewell expressions. It was made clear that the study was completed, and although participants would be able to keep the new fully-adjustable workstations, that the uniqueness separating them from the rest of their peers was also over. Even the management, except for the Service Center

TABLE 7. Participants’ Self-Assessments—VAS Values—Means and Confidence Intervals

Self-Assessment	Commencement	30-Day Post-Test	1-Year Post-Test
Job satisfaction	53.96 (7.59)	51.19 (6.27)	52.58 (6.98)
Physical—other	64.46 (11.63)	61.81 (12.78)	53.04 (11.02)
Stress—other	56.19 (11.39)	64.84 (11.13)	57.92 (10.50)
Unscheduled breaks	45.77 (12.64)	54.85 (11.82)	59.08 (12.00)
Opportunity to learn	40.58 (10.61)	34.54 (8.08)	38.85 (9.54)
Job security	36.77 (9.63)	45.31 (8.85)	35.73 (7.60)
Income	35.73 (7.59)	41.73 (5.83)	44.31 (6.38)

Notes. VAS—Visual Analog Scale.

Director, believed there would be no return of the investigators, no further contact, and thus routines were resumed.

For a period of 6 months there was purposely no contact of any sort between investigators and the targeted branch: employees or managers. After that period, and 18 months after the onset of the ergonomics study, a principal investigator returned to conduct post-study individual and group interviews to obtain participants' self-assessments of their physical and psychosocial status. Twenty-three of the 26 participants were present for this follow-up. One had retired, another was out on leave, and the third had been transferred to another department and was unable to attend the interview sessions.

All 23 perceived their physical improvement as good as or better than it had been at the conclusion of the study 6 months earlier. They indicated internalization of the healthier work habits, e.g., work postures, moving around when needed, frequent workstation adjustments throughout the day, etc. In fact some employees said they showed some of their colleagues who were not part of the study better ways to arrange their workstation and their postures.

Reports of maintaining the physiological gains achieved in the study in the absence of continued or further special attention, indicates the benefits of the ergonomic interventions. Likewise, psychosocial benefits were also apparent. The prevailing sense of well-being gained from the ergonomic interventions was indicated by comments such as, "I no longer dread coming to work any more: I even look forward to it" although the tasks, the management, and the pressures remained the same. A few of the participants experienced bolstered self-esteem and applied for and obtained better positions within their branch.

The follow-up interviews, 6 months after the study conclusion and 18 months after the onset, clearly confirms that establishing an optimal ergonomic environment can reap long-term physiological and psychological advantages that benefit both the employee and the employer.

5. DISCUSSION

Results from the selected critical variables indicate a remarkably clear and consistent pattern of evidence indicating the effectiveness of the ergonomic intervention. This pattern is based on several independent sources of measurement.

The physical examination, which involved relatively objective assessments of physiological signs of musculoskeletal disorders, revealed a dramatic drop in the number of such signs following the intervention—a drop which was maintained for a period of 1 year. These physiological results were identical to those observed in the participants' combined ratings of intensity and frequency of musculoskeletal pain, and for each of the symptoms of visual problems. There were two further indications that intervention led to healthier and more efficient working postures. First, direct measurement of head and trunk angles showed a decrease in the amount of flexion (awkward forward bending). This was confirmed by a parallel decrease in the ergonomist's standardized assessment of indicators of static load. Second, two indicators of the participant's own assessment of the ergonomic adequacy of the workplace—seat comfort and adjustability of keyboard support surface—showed dramatic increases following the intervention.

This pattern of results supports the conclusion that the ergonomic intervention was highly effective. The combination of training plus highly adjustable equipment produced a measured improvement in working posture along with a perception by the participants that their work environment had in fact been improved. The hypothesis was that this improvement in working posture would, in turn, reduce musculoskeletal load and produce a consequent drop in signs and symptoms of musculoskeletal disorder. These drops were observed. Finally, the decrease in visual problems seems to indicate that the optometric intervention was likewise effective.

Examination of the two unexpected results suggests that neither seriously contradicts the aforementioned conclusion. The observed increase in arm flexion can be attributed to a required readjustment in working posture due to the new configuration of the keyboard. If this increase in

flexion had actually increased musculoskeletal load, we would have expected an increase in signs and symptoms of shoulder discomfort. In fact, exactly the opposite occurred. Evidence from the physical examination, subjective reports, and partial results from the EMG data suggest that, in this case the higher flexion levels represented a beneficial adaptation to a new work place configuration.

With regard to the problem of increased EMG load in the 1-Year Post-Test, we have no definitive answers. We observed a distinct increase in the amount of time the EMG signal was below 1%MVC immediately following the intervention. This effect is considered a critical indicator of reduced load [3]. We believe that the results from the 1-Year Post-Test represent either an equipment malfunction or the occurrence of some stressful event during this period affecting all participants, which might have raised their resting levels. However, if a stressful event had occurred, it was not detected in the psychosocial questionnaire responses. In either case, the most reasonable strategy is to discard the 1-Year Post-Test, and accept the results from the first two recording periods, which are completely consistent with the remaining pattern of results.

With regard to psychosocial factors themselves, it is of some interest that while the psychosocial questionnaire responses did not appear to reflect the impact of the intervention, the follow-up interviews clearly showed positive psychosocial benefits. However, literature repeatedly demonstrates the interaction and the confounding of physiological and psychological components in measuring workers' health (e.g., [4, 5, 6]). For example, a measurement scale developed to assess ergonomic factors such as movement [7, 8], conceptualized to determine physical aspects of the environment, was perceived by the responders more as a psychosocial aspect. The movement scale included the following items: (a) Do you hold your arms in one position for long periods of time when performing your job? (b) Does your job allow you to change positions and sit and stand when you want? (c) At work, do you sit or stand in the same position for several hours? Surprisingly, this scale was found to measure the psychosocial

component of having control over one's work more than the physiological strain of static positions. Therefore what was anticipated as a simple ergonomic measurement of how much employees move about during their work was an example of the complexities of employees' perceptions and reactions to their organizational climate as well their physical environment. Likewise, the present study gains from an optimum ergonomic environment that encompasses the psychosocial, organizational, and physical components.

At a more general level, this investigation is considered a quasi-experiment in that it lacked a comparison group that did not receive an ergonomic intervention. As such, the obtained results might be subject to question on the basis of threats to internal validity and demand characteristics [9]. Are these threats reasonable?

We first examine the possibilities of investigator bias and expectation. Clearly the investigators expected a better result after the intervention and this might have biased their professional judgments. However, no investigator during the second and third assessments had available any of the previous individual assessment records. Approximately 2–3 months elapsed between the first two assessments and 1 year elapsed between the second and third assessment. There were six different professionals involved at various stages in the assessment. For bias to be operative it would have required all of these individuals to recall their previous judgments on each participant and adjust them upwards. This does not seem a reasonable possibility.

A similar argument may be made in terms of participant demand characteristics. Did the ratings of the participants after the intervention represent their awareness that we "expected" them to have more positive ratings? Again, we mention the time frame and the fact that all subjective ratings were carried out using the 100-mm VAS. For this bias to be operative, it must be assumed that participants recalled the scale location of their previous responses and adjusted them accordingly. This is logically possible, but seems unlikely. We must point out that the positive results from EMG (at least for the first two periods of observation) and the measured postural angles would also

contradict the supposition that the positive results are simply due to bias.

A third kind of threat to internal validity to be evaluated is that of time-related events which co-occurred during the course of intervention and might have affected the results [9]. In fact, organizational changes did occur during the period of the post-intervention assessment which had the potential to negatively impact the participants. However, it would have been expected that any psychological stress associated with this potential (see, e.g., [10]) would have worked against our overall positive impact which was observed long after the actual intervention.

On the other hand, selection bias is a threat to internal validity that must be taken more seriously. The participants in the study were all volunteers and therefore might have been predisposed to regard ergonomic improvements more positively. This is a relevant criticism since we might expect that if the intervention had been imposed as a management directive, the results might have been less positive. Of course, it would not have been possible, on ethical grounds, to carry out this study without the participants' voluntary consent. In terms of the practical question of implementation of effective interventions, employee participation in intervention planning would be a way to bridge the conceptual gap between volunteers in a research study and an imposed management solution.

Finally, we must address the question of Hawthorne Effects. These have traditionally been described as positive outcomes resulting from simply paying attention to study participants. There are two responses to this question. First, it is certainly the case that our participants chose to participate in the study and that they received a certain degree of individualized attention in terms of ergonomic training and coaching. However, we strongly argue that such attention was an essential component of the intervention. It would have been illogical to design an assessment of an ergonomic intervention involving extensive workplace redesign without providing participants the requisite associated training. It seems equally illogical to argue that the complete range and duration of positive effects obtained in this study

was strictly the result of paying attention to the participants, rather than the specific equipment and related training. Moreover, there is now convincing evidence that the Hawthorne Effect itself (the "paying attention" explanation) was most likely a misinterpretation of the original study and that this misinterpretation has been uncritically carried forward in generations of textbooks (see [11, 12]).

6. CONCLUSIONS

The combination of positive and long-lasting results from multiple dependent variables—both subjective and objective—leads to a consistent conclusion that the ergonomic intervention reduced both musculoskeletal load and visual complaints. However, the scope of the intervention was extensive and costly. To what extent can the results of such an extensive intervention be considered a model for future efforts—particularly in terms of costs and benefits?

First, there is now an extensive literature documenting the beneficial effects of ergonomic interventions. Some of these studies have focused primarily on physical ergonomics—seating, workstations and lighting. Dainoff [13], Francis and Dressel [14], and Sullivan [15] have each documented specific tangible benefits in term of increased productivity resulting from the employment of well designed ergonomic equipment (see also [16]). The most carefully documented analysis of the cost-effectiveness of an ergonomic intervention is that of Aarås and his colleagues [17]. They determined that, over a 9-year period, the savings to the company resulting from the ergonomic intervention were over 850% of the initial investment.

In the detailed cost-benefit analysis reported in the work of Spilling and his colleagues, just cited [17], it is of considerable interest that a large fraction of the savings resulting from the ergonomic investment can be attributable to a reduction in what are normally considered overhead items: training costs for replacement workers, medical expenses, sick leave, etc. In a compelling discussion regarding organizational barriers to technological innovation, Cyert

and Mowrey [18] point out the paradox that, while initial benefits to an organization from a technological innovation are typically found in reduced overhead, most organizational accounting systems are not set up to track these effects. The data of Spilling et al. [17] would appear to provide additional support for this argument in the sense that an ergonomic intervention is one example of technological innovation. Thus, in assessing the costs of a technological system against the presumed benefits, it is essential not to overlook a large class of such benefits—namely, reduced overhead costs.

Finally, it is important that ergonomic interventions not be examined in isolation, but considered part of the broader organizational context. Barge and Carlson [19] have documented that costs of managing employee disabilities may vary by as much as a factor of 10 among companies within the same industry group. Those companies who were consistently low in disability costs were characterized as having a positive proactive approach toward safety and accident prevention, wellness, and open employee communication. Westin [20] describes how a corporate ergonomic program embedded within such a proactive “people first” program was able to virtually eliminate cumulative trauma disorders at Federal Express during the period 1986–1990.

Relating all that has just been said to the current study, we note that, early in the study, two of the participants reported musculoskeletal problems that, while not disqualifying for inclusion in the study, were serious enough to represent potential disability. After the intervention, both individuals reported that their problems had been greatly alleviated. We estimated that the basic cost of the intervention—equipment plus training—was approximately US \$2,200 per participant. However, if the only effect of this project was to halt the progress toward two workers’ compensation cases, and we calculated the full cost of a single such case (see earlier) which some have estimated as high as US \$75,000, we might argue that even this demonstration project has paid for itself.

The observed positive results from this study, together with the cost-benefit arguments just discussed, allow us to comfortably recommend that

an ergonomic program should play an important role in the modern organizational environment. Such a program, if thoughtfully implemented, has the potential to significantly impact organizational productivity. This will typically occur first through a reduction in overhead, but can later have more direct effects (see [21] for examples).

However, the organizational context within which an ergonomic program is embedded is crucial. It is critical that such programs not end up as a lock step system of automatic checklists, or the results may well be counterproductive. For example, the specific ergonomic components of the present study were based on the particular needs of a group of employees doing data entry from paper copy on rather old computer equipment. Other work environments, particularly those which are mouse-based, might involve different solutions. We regard ergonomics as primarily a process of problem solving rather than the application of a fixed set of rules.

Particular attention must be paid to the psychosocial context of the program. We have referred to the intimate relationship between musculoskeletal load and psychosocial stressors. As Smith and Sainfort [10] have pointed out, the physical discomfort from a poorly designed work environment may become a source of psychological stress which, in turn, can directly act back upon the musculoskeletal system, further increasing the level of strain. Thus, the way in which physical ergonomic solutions are introduced becomes crucial. We believe that our approach to training/coaching played a major role in the success of our intervention. Not only were the participants given an understanding of the basic principles underlying their new equipment, but we made a sincere effort, through frequent coaching visits, newsletters, etc., to insure that each was empowered to use the equipment adjustability available to control and solve her own individual postural problems. By giving the employees some degree of positive control over their own work environment, which they were able to generalize to other aspects of their work environment, we have provided a powerful psychosocial benefit as well.

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