REVIEW ARTICLE

Occupational Stress in Human Computer Interaction

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Abstract: There have been a variety of research approaches that have examined the stress issues related to human computer interaction including laboratory studies, cross-sectional surveys, longitudinal case studies and intervention studies. A critical review of these studies indicates that there are important physiological, biochemical, somatic and psychological indicators of stress that are related to work activities where human computer interaction occurs. Many of the stressors of human computer interaction at work are similar to those stressors that have historically been observed in other automated jobs. These include high workload, high work pressure, diminished job control, inadequate employee training to use new technology, monotonous tasks, poor supervisory relations, and fear for job security. New stressors have emerged that can be tied primarily to human computer interaction. These include technology breakdowns, technology slowdowns, and electronic performance monitoring. The effects of the stress of human computer interaction in the workplace are increased physiological arousal; somatic complaints, especially of the musculoskeletal system; mood disturbances, particularly anxiety, fear and anger; and diminished quality of working life, such as reduced job satisfaction. Interventions to reduce the stress of computer technology have included improved technology implementation approaches and increased employee participation in implementation. Recommendations for ways to reduce the stress of human computer interaction at work are presented. These include proper ergonomic conditions, increased organizational support, improved job content, proper workload to decrease work pressure, and enhanced opportunities for social support. A model approach to the design of human computer interaction at work that focuses on the system "balance" is proposed.

Key words: Human computer interactions, stress, job design, technology implementation, work organization

Introduction

This paper will review evidence that the use of computers at work can lead to stress. The widespread introduction of computers and information technology at work has produced

a profound impact on the design of work processes. In some ways computerized jobs have become more complex and require greater skill. However, for the majority of computer workers, jobs have become simpler and less challenging, and this has led to increased stress. By the year 2000 more than one-half of the workforce in all developed countries will be working with computers as a substantial part of their

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job¹⁾. This trend will accelerate in the future since computers provide the following advantages: (1) lowered production costs through the use of more efficient machines, (2) reduced workforce, (3) a less skilled and cheaper workforce for most of the redesigned jobs, (4) improved product quality and conformity, (5) increased “up-time” or productive time, and (6) enhanced flexibility of the production system to meet changing market needs²⁾. Computers produce efficiencies, competitive advantages, and the ability to carry out work processes that would not be possible without their use.

Experience with earlier forms of factory automation indicate that some of these advantages, such as workforce reduction, lower pay, and simplified jobs, can adversely affect quality of working life, and may not be in the best interests of the employees’ welfare. Computerized jobs require little physical energy expenditure, tend to be sedentary, and often require substantial cognitive processing and mental attention. But, the production demands can be high, with constant work pressure and little decision making possibilities. These are conditions that have been shown to produce occupational stress²⁻⁷⁾. The transition from more traditional forms of work to computerization has been difficult in many workplaces, and has resulted in significant psychosocial and sociotechnical problems for the workforce. These issues will be discussed in detail below, and recommendations for more effective computer automation implementation strategies and work design improvements

will be suggested.

The deployment of millions of computers in thousands of workplaces around the world has resulted in high levels of complaints from workers about the visual and musculoskeletal demands imposed by working at a computer⁸⁻¹²⁾. After several years of research, there is a growing consensus that poor workstation design coupled with high workload, postural demands and job demands can contribute to shoulder, neck, back and wrist/hand discomfort and pain, as well as fatigue for many computer users. Improper illumination and glare, work demands, computer screen design, and task characteristics can contribute to visual discomfort. Also, improper work organization and job design can lead to psychological stress.

The claims that working at a computer creates psychological distress are not new^{5, 13, 14)}. Figure 1 presents a model of how work organization factors are related to psychosocial perceptions and stress. Negative psychosocial perceptions can lead to stress reactions that may lead to adverse health outcomes. This model is described in more detail in Smith and Sainfort⁷⁾, and more complex pathways are explained in Smith and Carayon¹⁵⁾. In general, work system factors such as work organization or technology have the potential to produce immediate stress reactions which are modified by a worker’s personal characteristics and susceptibilities. If these short term stress reactions become chronic, they can lead to significant adverse health outcomes.

Fig. 1. A general model of job stress and strain⁸¹⁾

Theories of stress define the mechanism of how these outcomes can occur.

Theories of Stress

Stress is a biological process by which the body attempts to adapt to some challenge by mobilizing its energy, disease fighting and survival responses¹⁶⁾. Selye defined the medical consequences of stress on the immune system, gastrointestinal system and adrenal glands. There are also psychological and perceptual processes involved in stress reactions. Lazarus^{17, 18)} defined physiological changes resulting from emotions due to perceptions of threats. The quality or intensity of the emotional reaction and its resultant physiological and behavioral changes depend on the cognitive appraisal of the present or anticipated significance of the interaction with the environment or its “threat” to security and safety.

Levi¹⁹⁾ linked “psychosocial stimuli” to disease when there was chronic exposure to adverse working conditions. Adverse psychosocial stimuli have the potential to act as stressors. In accordance with a “psycho-biological program”, psychosocial stimuli may evoke physiological responses similar to those described by Selye that in turn can lead to disease if the stress is chronic. Several intervening variables (individual characteristics, coping strategies or social support) moderate the link between psychosocial stimuli and disease.

According to Smith and Sainfort⁷⁾, stress results from an imbalance between various elements of the work system. This imbalance produces a “load” on the human response mechanisms that can produce adverse psychological and

physiological reactions. The human response mechanisms, which include behavior, physiological reactions and cognition, act to bring control over the environmental factors that are creating an imbalance. These efforts, coupled with an inability to achieve balance, produce overloading of the response mechanisms that lead to mental and physical fatigue. Prolonged exposure and fatigue leads to strain and disease. This model emphasizes sources of occupational stress (i.e. stressors) that can be manipulated to produce proper balance in the work system. These stressors can be categorized into the following elements of the work system: (1) task, (2) organizational context, (3) technology, (4) physical and social environment, and (5) individual characteristics (see Fig. 2).

There are potentially many ways that job stress can affect the risk of worker ill health. First, there are the bio-physiological stress reactions that can adversely affect healthy tissues, exacerbate the effects of physical strain or limit the ability of the body’s defense and repair systems to deal with micro trauma. The second influence is the effects of stress on the behavior of the individual that may increase adverse exposures or decrease the motivation to seek help when injured. The third is the general psychological and physical sensitization of the worker by exposure to job stress. This may lead to greater perceived pain and poorer overall health and vital capacity.

Research Findings about Stress and Computer Use

Some of the early computer studies indicated that computer

Fig. 2. Model of the work system of computer users (adapted from Smith and Sainfort⁷⁾)

use was correlated with greater job dissatisfaction and distress^{5, 20–22}. Other studies found no additional distress due to computer use^{23–26}. More recent findings suggest that the design of computerized work systems influence job design, organizational policies, management practices and career opportunities, which can be determining factors in psychological distress^{2, 5, 14}. Studies by Bradley²⁷, Westlander²⁸, Aronsson²⁹, Stellman *et al.*³⁰, and Carayon-Sainfort³¹ have demonstrated that the introduction of computers into the workplace was associated with substantial changes in the work processes, social relationships, management style, and the nature and content of job tasks. Some of these changes were beneficial, yet many had adverse effects on physical and mental health.

A selection of studies that are illustrative of research into occupational stress and computer work, which are taken from the several hundred such studies in the literature, are presented next. The studies have been divided into six categories: laboratory studies, cross-sectional studies of computer users, longitudinal studies of computer users, comparative studies of computer users to non-users, longitudinal studies of computer implementation, and studies of computerized electronic performance monitoring.

Laboratory studies

The following laboratory studies of computer users and stress are illustrative of the studies that have been conducted. Yamada³² studied attention, mental workload, fatigue and interest, both in VDT work at the workplace and in playing video games at home through the measurement of frontal midline theta rhythm (Fm-theta) and eye blinking. The subjects for one experiment were ten undergraduates and ten Japanese abacus experts, both with normal vision. The subjects' task was to identify and count non-vocally the target letters in a stimulus set as quickly as possible. The results indicated that the abacus experts showed greater amounts of Fm-theta during the visual search tasks, and amounts of Fm-theta increased as a function of memory set size. The results of blink rate showed that the mean eye blink rate during the task decreased from the pre-task rest period. The results suggest that the task demands inhibited blink activity during the visual search task. It was concluded that the amount of Fm-theta and eye blink rate appeared to be good indices of attention/concentration of a mental task using a video display terminal. These measures may represent physiological stress reactions that support the belief that stress is related to work demands.

In a psychophysical study of different working conditions,

Rau³³ examined the relationship between psychophysical measures and perceptions of work in thirty-six electrical engineers and twenty-four skilled workers in the field of electrical engineering. The subjects were tested on a computer simulated electroenergy network task. The simulated work was comparable to real life in terms of technical equipment and information transfer used. The operators worked in two person teams (i.e. a shift leader with decision authority and a co-operator) and performed simulated work for three hours. Measures included heart rate (HR), blood pressure (BP), and motor activity, as well as perceptions of strain, affect, motivation, locus of control, and feeling of success. The three types of tasks compared had low demand/low decision latitude (LL), moderate demand/high decision latitude (MH), and high demand/high decision latitude (HH). The results showed that subjects perceived more exhaustion/strain and mental load during HH tasks compared to MH or LL tasks. Also, HR was lower during LL tasks than HH tasks. Shift leaders showed higher HR and BP than co-operators during HH tasks. Further, shift leaders showed less HR deceleration than co-operators during the LL tasks. In all three tasks, co-operators perceived more control and success than shift leaders.

Yamamoto and Matsuoka³⁴ used 10 subjects performing word processing tasks in a laboratory study to examine how event-related potential, and more specifically, the contingent negative variation (CNV), could be used to measure the mental stress of VDT operators. The results showed that the pre-task negative potential area was greater than the post-task negative potential areas. To examine whether the word processing task itself was responsible for the change in CNV, five of the original subjects repeated the experiment doing a reading task instead of word processing. There was no difference between the pre-task and post-task negative potential areas for the reading task, suggesting that the word processing task represented a high mental load or high stress task.

Schleifer and Amick³⁵ had 45 female professional typists perform a data entry task in four different conditions in order to examine the effects of computer response time and incentive pay on mood disturbances and musculoskeletal discomfort. The conditions were rapid response time with no incentive pay (RR/NI), slow response time with no incentive pay (SR/NI), rapid response time with incentive pay (RR/I), and slow response time with incentive pay (SR/I). The study was conducted over four days (the last three were included in the analysis), with two sessions per day (i.e. morning/afternoon), and three 50-minute work periods

per session. The results focusing on response time revealed that the feelings of frustration and impatience that increased across the workdays were greater for the subjects in the slow response time conditions. Also, increases across the workdays for feelings of rush and tension were greater for subjects receiving incentive pay, though feelings of fatigue were greater for subjects not receiving incentive pay. When time was examined, the results showed that visual and hand/arm discomfort increased across the workdays, and mood disturbances and musculoskeletal discomfort increased from morning to afternoon and over the periods.

Heart rate and blood pressure measures were also taken during the previously described study³⁶. There were no differences in heart rate between subjects in the slow and rapid response time conditions across workdays. However, in comparison to day 2, the variance of the inter-heartbeat interval was lower for incentive pay subjects than non-incentive pay subjects on day 3. Also, both the inter-beat intervals and the variance in the inter-beat intervals decreased from the morning to afternoon sessions, but they both increased over the periods. The results of the blood pressure data showed no differences due to system response time. On the other hand, blood pressure was higher for incentive pay subjects compared to non-incentive pay subjects on day 4 as compared to day 2.

Breathing is another psychophysiological measure that has been used to measure stress. Schleifer and Ley³⁷ conducted an experiment to evaluate end-tidal PCO_2 as an index of psychophysiological activity. Heart rate and mood disturbances were also assessed. The three conditions that were compared were a 5-minute baseline level of relaxation, which was followed by 5 minutes of progressive muscle relaxation, and then 120 minutes of VDT data entry work. The three sets of conditions occurred in the morning and afternoon. The results indicated that end-tidal PCO_2 was lower and respiration rate higher during the work period than during either the baseline or the muscle relaxation period. Also, inter-heartbeat interval was smaller for the work period compared to both the baseline and muscle relaxation periods. In addition, feelings of relaxation were lower and feelings of tension were higher during the work period than during either of the two relaxation periods.

Cross-sectional studies of computer users

Carayon-Sainfort and Smith³⁸ and Carayon-Sainfort³¹ studied the effects of the frequency of computer problems and computer use intensity on employee perceptions of task characteristics and worker stress. The study was cross-

sectional in design, and sampled 262 office workers from three organizations using a self-report questionnaire. Results indicated that computer problems (such as breakdowns) and computer use intensity had indirect effects on worker stress through their influence on task characteristics such as workload, work pressure, and job control. A high frequency of computer problems and computer use intensity were related to feelings of high workload, high work pressure, and low job control. In turn, high workload and work pressure, and low job control were associated with high daily life stress. Work overload has also been identified as a moderator of the relationship between Type A personality and well-being³⁹. More recent research has confirmed that computer hassles are related to psychological stress (somatization/anxiety)^{40, 41}.

In a similar study, Asakura and Fujigaki⁴² examined the direct and indirect effects of computerization on worker well-being and health in a sample of 4400 office workers. The results of their study confirmed those of Carayon-Sainfort³¹. For male participants, the effects of computerization on employee well-being and health were almost entirely mediated by the effects of job characteristics (though there were two direct effects). The results for female participants indicated that the effects of computerization on employee well-being and health were entirely mediated by the effects of job characteristics (i.e. there were no direct effects of computerization on well-being and health).

Lindström⁴³ conducted an extensive analysis of VDT use and its effects on job design for 1,124 banking and insurance employees using a self-report questionnaire. This study examined the association of VDT use, job demands, and job characteristics on employee well-being. Specific analyses were conducted on the differences between the occupational subgroups of customer service employees, office employees, ADP experts, and managers and supervisors.

For the entire group, a large amount of daily VDT work, computer breakdowns, slow computer response times and poor access to the data terminal were related to psychic symptoms and fatigue, feelings of a lack of competence, and nonspecific somatic health complaints. VDT variables were related to symptoms differently for the various job groups. For office employees, computer breakdowns, computer scheduling of work, and unsatisfactory mastery of VDT applications were related to psychic symptoms and fatigue. Among managers and supervisors, only unsatisfactory mastery was significantly related to psychic symptoms and fatigue. Nonspecific somatic symptoms were related to increased VDT work and more problems in VDT use for the entire group of users. Haste and more difficult

tasks were related to all four symptom categories: psychic symptoms and fatigue, lack of competence, unspecific somatic complaints and sleeping disturbances. Lack of variety in work content was related to psychic symptoms and fatigue, lack of competence, and unspecific somatic complaints. Poor coworker relations were related to unspecific somatic complaints and sleeping disturbances.

Polanyi *et al.*⁴⁴⁾ studied factors related to upper limb work-related musculoskeletal disorders (WMSD) among 1,007 newspaper employees responding to a cross-sectional survey. There were five variables that were independently associated with WMSD symptoms: gender, time spent keyboarding, deadlines, psychological demands, and social support. Women were over two times as likely to have a WMSD than men. Increased daily time spent on a keyboard, increased deadlines, and increased psychological demands were related to an increased probability of having a WMSD. Increased social support decreased the probability of having a WMSD.

In another study of newspaper employees, Bernard *et al.*⁴⁵⁾ used a cross-sectional survey of 973 workers to examine the relationship between VDT exposure variables, psychosocial variables, and musculoskeletal discomfort. Analyses were conducted for the full sample, as well as for one job type that had a comparable number of males and females ($n=150$). For the whole sample, the predictors of neck symptoms included the number of hours spent under deadline, changes in workload, and lack of importance for ergonomic issues by management. The predictors of shoulder symptoms included a lack of participation in job decisions and employer tenure, and the predictors of hand/wrist symptoms included the numbers of hours spent typing per day, the number of hours spent under deadline, and a lack of supervisor support. Analysis of the sub-sample revealed different results. The number of hours spent under deadline and lack of importance for ergonomic issues by management were the only predictors of neck symptoms, the number of hours spent typing per day was the only predictor of hand/wrist symptoms, and there were no predictors of shoulder symptoms.

In a similar study, Hales *et al.*⁴⁶⁾ used a cross-sectional survey of 533 telecommunications employees who used VDTs to examine the relationships between VDT exposure variables, psychosocial variables, and musculoskeletal discomfort. Again, psychosocial stressors were the main predictors of musculoskeletal discomfort. A lack of decision making opportunities, fear of being replaced by computers, and high information processing demands were among the predictors of neck symptoms. Fear of being replaced by a

computer and the number of times rising from one's chair predicted shoulder pain. Also, having a thyroid condition and high information processing demands predicted hand/wrist symptoms.

Smith *et al.*⁴⁷⁾ and Conway *et al.*⁴⁸⁾ studied the effects of psychosocial aspects of working conditions on mood disturbances, musculoskeletal health complaints and sickness absence from work in 396 civil service state employees in three agencies. Employee perceptions of several work organization factors were examined using a questionnaire. Higher perceived workload was related to more employees reporting back and hand pain. Lack of job control and low participation were related to more employees reporting hand pain. Concern about job future was related to more employees reporting back pain. Low social support was related to more employees reporting elbow pain. Tension-anxiety was related to more employees reporting back, elbow and hand pain. The specific work organization factors did not influence employee reports of tension-anxiety. Both the work organization factors and tension-anxiety influenced musculoskeletal pain directly, without modifying or interacting effects with each other.

Longitudinal studies of computer workers

Longitudinal studies of computer workers have added a temporal dimension to the study of working conditions, computer use, and health. Carayon *et al.*⁴⁹⁾ conducted a three-year longitudinal study of office workers in a public organization to determine the relationship between job factors and employee stress. One hundred seventy-seven employees participated in the first year, 151 in the second year, and 148 in the third year. The results indicated that employee perceptions of job design and the extent of stress varied over time. For the first year of data collection, quantitative workload, work pressure, and supervisor social support were the most important predictors of employee stress. For the second year, task clarity, supervisor social support, and job future ambiguity were the most important predictors. For the third year, task clarity, attention, and job future ambiguity were the most consistent predictors. This shows that while there was some consistency in the structure of the relationships between job design considerations and the level of employee stress, the specific job design factors that were related to particular stress outcomes, such as anxiety or somatic complaints, differed over time.

Fujigaki⁵⁰⁾ conducted a prospective evaluation of job-event, life event, and depressive symptoms for ten male computer software engineers. Observations were made every two

weeks for five months and every week for the next two months. Daily and weekly contents of work were surveyed using a diary method. Semi-structured interviews were also held on each sampling day. The job events that were scored were the presence of time pressure/deadline, work overload, amount of work increase, responsibility increase, and trouble with clients. The analyses compared the mean depression scores when job events were present vs. absent. The results showed that depression scores were higher on days that job events were present over the entire sampling period. Also, depression scores remained higher one week after job events were present.

Fujigaki and Mori⁵¹⁾ also collected data on biochemical reactions (i.e. urinary catecholamines and salivary cortisol) and psychological reactions (depression, anxiety, arousal, drowsiness, and degree of busyness) for the same study participants⁵⁰⁾. The results showed that increases in adrenaline were associated with job events such as starting new projects, time before a deadline, sudden increase in amount of work, and negotiation of budgets. Increases in cortisol were related to the continuation of overtime, finishing a big project, and getting used to a job. In addition, adrenaline was negatively correlated with drowsiness, pain, anxiety, and depression, while cortisol was positively correlated with busyness and overwork.

Lindström *et al.*⁵²⁾ conducted a longitudinal study of work characteristics and health complaints related to VDT work. Three departments of the head office and 11 branch offices of one Finnish insurance company were the sample for the study. After three rounds of data collection (1985, 1987, 1993), 144 of the original 477 employees remained in the study. These 144 employees who participated in all three study phases constituted the follow-up group. A structured questionnaire was used to collect the data. Results showed that the daily amount of VDT use increased continually during the follow-up. Psychological symptoms correlated with eye discomfort, and neck and upper limb complaints. A large amount of daily VDT work was related to high attention and psychomotor demands, as well as to high physical workload and low cognitive and social demands. The low cognitive and social demands were related to the amount of VDT work only in the first two study phases.

Computer breakdowns, slow response times, and dependence of work scheduling on access to a VDT were related to attention and psychomotor demands and physical workload in each study phase. In the second study phase, just after the implementation of a comprehensive online data system, those reporting disturbances in their VDT use also

reported a lack of content variety and control. Poor interpersonal relationships and job insecurity correlated with high dependence on access to a VDT application in the last study phase. Psychological symptoms and disturbances in the functioning of a VDT application were not consistent from one phase to the other. A large amount of daily VDT use, high disturbances associated with VDT application, and many years in VDT work were all related to more frequent neck, shoulder, and upper limb complaints in all three study phases. Quantitative workload was the main predictor of psychological symptoms for all study phases.

Comparative studies

Tanaka *et al.*⁵³⁾ examined the effects of different types of VDT work on levels of noradrenaline and adrenaline. Twenty-three subjects classified into young (mean=20 years old), middle-aged (mean=39 years old), and old (mean=65 years old) age groups, who had not been engaged in VDT work, participated as subjects. In the experiment the subjects performed a target word search task which varied by the presentation style: small letters on the VDT screen, large letters on the VDT screen, and words printed on a sheet of paper. There were no differences between the age groups in terms of error rate, pre-work adrenaline excretion rates, or changes in adrenaline excretion rates over the experimental day. In comparing results from the three different VDT tasks, it was found that there were no differences in error rates, but tasks were completed more slowly during the small letter task as compared to the hard copy task. None of the three tasks led to changes in adrenaline excretion rates over the experimental day. Noradrenaline excretion rates were different between tasks, with rates increasing after resting from a small letter task.

In a second study repeating their earlier study, Tanaka and Yamamoto⁵⁴⁾ again examined the effects of different types of VDT work on levels of noradrenaline and adrenaline, but this time only in young people (range=19–21 years old). There were no differences between task groups in pre-work adrenaline or noradrenaline excretion rates. During the experiment adrenaline excretion rates did not change significantly over the experimental day (i.e. from pre-work to post-work to rest) for any of the three tasks. Noradrenaline excretion rates decreased significantly from pre- to post-work for the hard copy task, and they increased significantly from post-work to rest for the small letter task. The results suggested that VDT workload might be worsened by small print size.

Murata *et al.*⁵⁵⁾ assessed the central nervous system effects

and visual fatigue induced by working with visual display terminals (VDT). The participants were 24 keypunchers of a life insurance company who performed VDT data entry tasks. This group was compared to six college students who were not performing VDT work. Measures of symptom frequency, visual evoked potential (VEP), critical flicker fusion (CFF) and near-point distance were taken before and after 2.5 hours of VDT work or lab work for the keypunchers and students, respectively. A trained public health nurse completed a questionnaire concerning subjective symptoms of fatigue for each subject. The 30 symptoms included in this questionnaire were divided into three groups: drowsiness and dullness (Factor 1), difficulty in concentration (Factor 2) and projection of physical impairment (Factor 3).

The number of complaints of subjective fatigue related to projection of physical impairment increased significantly in the 24 keypunchers over the course of the VDT work shift. A significant extension of visual near-point distance over the work shift was observed for the keypunchers. The VEP latencies were found to be significantly prolonged in keypunchers. The change in P100 latency during the 2.5 hour VDT work shift was inversely correlated with the number of years that the keypunchers had spent working with VDTs. On the other hand, there were no changes in any of the tests for the six non-VDT college students from before to after laboratory work. The changes observed between the first and second tests for both the N75 latency and subjective fatigue related to drowsiness and dullness were significantly larger in the keypunchers than in the college students. In addition, the mean CFFs on both the first and second tests were significantly lower in the keypunchers than in the college students.

Trimmel and Huber⁵⁶⁾ conducted a study of the after-effects of human-computer interaction by measuring the P300 component of the event-related brain potential (ERP). Forty-nine subjects participated in six experimental conditions. The conditions were formed by using two kinds of media (paper/pencil versus computer) and three types of tasks (text editing, cognitive, emotional). After each experimental condition there was an ERP task and a 1-minute pause. EEGs were recorded from the F3, F4, Cz, P3, and P4 locations. The results indicated greater P300 amplitudes for the paper/pencil condition compared to the computer condition at all locations except F3, where no difference was found. Greater amplitude appeared after the emotional task than after the other tasks. There were significantly shorter latencies after cognition-based conditions compared to text-based or emotion-based conditions.

Longitudinal implementation studies

Longitudinal research of the introduction of computers into workplaces has shown that both the computer technology and the implementation process can affect employee stress. Majchrzak and Cotton⁵⁷⁾ conducted a longitudinal study of employee responses as their job technology changed from low automation, mass assembly technology to computer-automated batch (CAB) manufacturing technology. The CAB jobs demanded more mental and visual skills and less physical skills than the old assembly jobs. Those employees who took the new positions were volunteers and were given no special training classes to acquaint them with the new technology. The change from mass production to CAB technology increased the level of automation and informal communication opportunities, and decreased workflow integration and employee control over the quality of the process. An equal number of employees responded positively and negatively to the technological change, while a large proportion of employees reported experiencing no changes. For some employees there were psychological stress disturbances. Job satisfaction was enhanced to the extent that work-cycles were sufficiently short and sufficiently predictable to preclude the need to work with others. A generalized feeling of a better quality of life was created when the job transfer provided for more control, more routine, and more coordination.

Huhtanen and Leino⁵⁸⁾ conducted a three-year longitudinal research program examining technology changes in banking and insurance companies. Two insurance companies and four banks were examined, with 1,744 employees taking part in 1985 and 2,134 responding in 1987. During the study period, new electronic payment systems that were based on customer self-service were installed in the banks. Employees were asked to estimate the impact of the new technology on job characteristics as they related to mental well-being. The questions were asked before the systems were installed and then again two years after the new technology had been implemented. The findings presented here represent those 803 employees who participated in both the 1985 and the 1987 data collections. The results indicated that employee perceptions of the effects of the new technology before it was installed changed after the technology was actually introduced. The level of interest in work, opportunities to use one's abilities, and work pace were perceived as increasing more than expected. The monotony of work did not increase as much as expected. The way that the jobs were organized by the technology had an influence on both the quantity and quality of the

work production after implementation. Various occupations were differentially affected by the new technology. The data experts felt that their work pace had increased as a result of the new systems, and the customer service employees, office workers, and the VDT workers felt the difficulty of the tasks increased more than was expected.

Korunka and his colleagues⁵⁹⁻⁶¹⁾ conducted a longitudinal investigation of the effects of introducing a new computer technology on psychosomatic complaints, strain, job satisfaction, and hormone excretion. Measurements were taken two months before and twelve months after the conversion of the job environment to new computer technology. A self-report questionnaire was used to collect information from 171 employees that were working in seven different companies. The focus of Korunka *et al.*⁶¹⁾ was to examine the effects of the implementation process itself on employee well-being. Employee participation in the implementation process led to higher levels of acceptance of the new technologies, and lower levels of dissatisfaction and stress. Karsh⁶²⁾ obtained similar results in a study of government employees who had recently started using imaging technology. Furthermore, in those companies that had employee participation, stress was reduced between the time of two months prior to the implementation and one year later, while there was no change in the levels of stress for employees who could not participate.

Korunka *et al.*⁶⁰⁾ also looked at the effects of the new technologies on job satisfaction and psychosomatic complaints. The results showed that highly monotonous work was associated with increased psychosomatic complaints and less job satisfaction. A higher level of participation in the change process was associated with greater job satisfaction after the introduction of the new technology. In those companies with low employee participation in the implementation, there was a significant increase in psychosomatic complaints and a significant decrease in job satisfaction after technology implementation. Job satisfaction increased when the work with new technology was diversified and called for high skill qualifications, but tended to decrease for employees with low skill qualifications who were doing monotonous work at visual display units. For the hormonal analysis, Korunka *et al.*⁵⁹⁾ monitored fourteen of the subjects throughout the study for catecholamine and cortisol levels. The introduction of new technologies was related to increases in catecholamine excretions, but not to increases of cortisol. Also, there were no increases in reported subjective strain over time.

To examine the effects of continuous implementations,

the authors of the second Vienna Study^{63, 64)} analyzed the relationships between implementation variables, decision latitude, workload, stress, dissatisfaction, and organizational outcomes. On the organizational level, their findings revealed that implementation project size, high user demands, and implementations that extensively changed the work structure of end users were all related to negative company effects (i.e. a combination of more overtime, budget conflicts, schedule delays, and customer complaints)⁶³⁾. On an individual level, subjects who had experienced recent implementation of information technology reported elevated levels of stress after the implementation when compared to their stress prior to the implementation. Also, participants with low decision latitude and high external workload were more likely to experience increases in stress over time (i.e. before-after the implementation)⁶⁴⁾.

In another longitudinal study of the relationship between computer technology implementation and physiological and psychological stress outcomes, Wastell and Newman⁶⁵⁾ examined the implementation of an ambulance control computer system by comparing job performance and stress before and after implementation. Prior to the implementation, the relevant tasks were conducted using pencil and paper. The job of the participants required operating in an uncertain, dynamic environment, with low spare capacity and high risk for error (death as a possible outcome for those needing an ambulance). These working conditions resulted in an acutely stressful job. External work demands were measured by counting the number of simultaneously active calls being handled by the dispatcher. The psychophysiological responses to these external pressures were measured using heart rate, blood pressure, anxiety, and fatigue. Post-implementation measurements were collected roughly four months after implementation. A total of 45 operational staff participated in the study. Results showed that the computer system improved response time to emergency situations. Systolic and diastolic blood pressures exhibited an increase for both the paper/pencil task and the computer-supported conditions as a function of increasing workload. The increases in systolic blood pressure with workload were steeper for the paper/pencil task. Anxiety and fatigue significantly increased with increasing workload for the paper/pencil task, while only anxiety increased in the computer-based task. It should be noted, however, that increased work levels in the control room after the implementation of the system made the comparison of stress levels before and after implementation problematic.

Boucsein and Thum⁶⁶⁾ studied cardiovascular,

electrodermal and electromyographic activity during eight hours of highly demanding computer work under different work/rest schedules, during system breakdowns, and during consultations. Eleven patent examiners who were members of a prototyping group using a new computer system for the examination of patent applications were participants in the study. Their jobs required complex decision-making and had high workloads. Measures of heart rate (HR), electrodermal activity (EDA) as skin conductance, and neck electromyographic (EMG) activity were taken continuously throughout the work day. Additional measures of respiration rate, pulse wave transit time (PW-TT) and gross body motions were recorded. Emotional well-being and musculoskeletal symptoms were each measured via 20-item adjective checklists. PW-TT was longest and HR lowest during system breakdowns. HR was highest and PW-TT lowest during consultations. Also, EDA steadily decayed during and after system breakdowns, but steadily increased during scheduled breaks. Neck muscular tension was lowest during scheduled rest breaks, but considerably increased during system breakdowns.

Hovmark *et al.*⁶⁷⁾ conducted a longitudinal study of the health complaints associated with computer work in three large industrial companies. During the first data collection, only a few of the employees had begun to work with the computer-aided design (CAD) system. The second data collection was carried out 1-year after all potential CAD employees had started CAD work. The participants at each time comprised the longitudinal study group of 151 CAD users and 50 non-CAD users. A questionnaire survey examined work demand, autonomy, social support, and health complaints. The results showed no significant differences between CAD and non-CAD users in health complaints at either time period. There was also no significant relationship between the amount of CAD work and the psychosocial aspects of work. Analysis of the longitudinal group of CAD users showed that there was an increase in complaints of the neck, shoulders, elbows and the musculoskeletal index between Occasions 1 and 2. There were associations during Occasion 1 between CAD working hours per week and both neck and eye complaints. During Occasion 2, there were associations between CAD working hours per week and neck and shoulder complaints. There were no significant relationships during Occasion 2 with other health complaints. There was no significant association between changes in health or psychological complaints and changes in CAD working hours per week.

Electronic performance monitoring

One specific type of computer software that has received a good deal of attention is electronic performance monitoring (EPM) technology (see Carayon⁶⁸⁾ for a review of EPM). EPM is typically used to monitor employee performance in computer tasks. Smith *et al.*⁶⁹⁾ conducted a questionnaire survey study examining the differences in stress responses between employees who were electronically monitored while doing computer work and those that were not. Both groups performed the same jobs. The results of surveys completed by 745 telecommunication employees showed that employees who had their performance electronically monitored perceived more stressful working conditions and more job boredom, psychological tension, anxiety, depression, anger, health complaints, and fatigue. The authors believed that the results might have been due to job design changes associated with the monitoring. In fact, when Carayon⁷⁰⁾ reanalyzed data from two job categories (service representatives, $n=225$ and clerks, $n=266$) from Smith *et al.*⁶⁹⁾, the results supported the proposition that EPM had an indirect effect on worker stress through its effects on job design.

Carayon⁷⁰⁾ also reported on a second study to specifically examine whether or not EPM had direct or indirect effects on worker stress. In it, 171 office workers averaging 7.2 hours/day working with a computer responded to the survey. The results revealed that monitored employees reported more supervisor feedback and control over work pace, and less job content than non-monitored employees. There were no differences between the monitored and non-monitored groups with regard to stress or health.

In a laboratory study, Schleifer *et al.*⁷¹⁾ examined the effects of EPM on mood disturbances and musculoskeletal complaints for employees that had low, moderate, and high task performance. Forty-seven females with clerical work experience served as subjects. In the EPM condition, keystrokes and error rates were monitored electronically and performance feedback was provided through the computer to enforce compliance with a set performance standard. The experiment lasted three days. Perceived time pressure and workload dissatisfaction increased from Day 1 to Day 3 for the EPM condition compared to the no-EPM condition in the low performance group. Perceived time pressure, irritation, and workload dissatisfaction increased from Day 1 to Day 3 for the EPM condition compared to the no-EPM condition in the moderate performance group. Perceived time pressure increased from Day 1 to Day 3 for the EPM condition compared to the no-EPM condition in the high

performance group. Right-hand and right-shoulder discomfort increased from Day1 to Day 3 for the EPM condition compared to the no-EPM condition for moderate performers, but there were no differences in musculoskeletal complaints in the other two performance conditions.

Summary of general findings from studies

Research studies on computer work and stress lead to the following general conclusions:

- ◆ Using a computer directly and indirectly produces increases in employee stress. The indirect effects are primarily mediated by job design factors.
- ◆ Computer tasks can produce physiological stress reactions such as changes in heart rate, blood pressure, catecholamine level, and brain wave activity.
- ◆ The strategies used to implement computer technologies (e.g. employee participation) can affect the level of employee stress.
- ◆ Computer users in less skilled jobs have greater amounts of stress than those in higher skilled jobs.
- ◆ When jobs are transitioned from one technology to a new one, those employees in less skilled jobs report more stress due to the new technology than employees in more skilled jobs.
- ◆ The specific job factors that produce stress vary according to the job category. However, there were several job stressors that consistently were stressful across different job categories. These were: (1) high job demands, such as heavy workload, work pressure and increased work pace, (2) a lack of control over the work process and/or an inability to participate in decisions, (3) a high level of task difficulty coupled with inadequate skills, (4) monotony, lack of variety or lack of task content, (5) poor supervisory relations or lack of supervisory support, (6) technology problems, such as computer slowdowns or break downs, which increase the perception of higher work load and less control, and (7) a fear for job security.
- ◆ Work organization factors influence psychological stress and mood states, and also have a direct influence on upper extremity musculoskeletal pain and discomfort.

A Model of Stress and Computer Use

To fully understand the health and safety implications of computerization, it must be realized that many working conditions jointly influence the stress of computer users. Smith and Carayon^{2,7)} have proposed a comprehensive job design model which illustrates the various aspects of working

conditions that can produce psychosocial stress. Figure 2 illustrates the components of the work system. There is an interaction among these workplace elements that produce physical and mental loads on the individual. It is the accumulation of the loads from these elements of work that influences the health and safety of computer users. A short description of this model of work elements follows.

Figure 2 illustrates a model for conceptualizing the various elements of a work system that can put demands (loads) on employees that may influence psychological and physiological reactions. At the center of this model is the individual with his/her unique physical characteristics, perceptions, personality and behavior. The individual uses technology, such as a computer, to perform specific job tasks. The characteristics and capabilities of the computer and other technologies affect employee performance, as well as the required skills and knowledge needed to effectively use the technologies. The task requirements also affect the skills and knowledge needed, while both the tasks and technologies affect variety, skill use, cognitive requirements and physical demands. The tasks, which define the use of technologies, are carried out in a work setting that comprises the physical and the social environment. The environment can affect employee comfort, psychological moods and attitudes. Finally, there is an organizational structure that defines the nature and level of individual involvement, interaction, control, supervision, workload, pay schedule, rest breaks, and performance standards.

This model, along with the model in Fig. 3, establish relationships between job requirements, psychological and physical loads, stress and health for computer users. Harmful demands lead to stress responses that can produce adverse psychological and physiological effects. These various elements of the work system interact to determine the way in which work is accomplished and the effectiveness of the work in achieving individual and organizational needs and goals. This is a systems concept in that any one element can influence any of the other elements. Smith and Sainfort⁷⁾ have given examples of how each element in this model has the potential to produce adverse stress and health effects.

Improving the Psychosocial Characteristics of Computer Work to Reduce Stress

Work organization and job design features of computer work that adversely influence job satisfaction, stress and health can be improved to reduce their adverse health consequences. As a first consideration it is important to

Fig. 3. Model of work system misfit (adapted from Smith *et al.*⁸²⁾)

recognize that computer work stress problems are seldom due to a single aspect of the organization, the job design or the technology. Rather, stress most often stems from a combination of several elements of the work system. This means that solutions for reducing or eliminating job stress must be comprehensive, and simultaneously deal with several different aspects of improper work design^{2, 72}. Solutions that focus on only one or two work design considerations will probably not succeed in controlling job stress problems. As a start for improving computer work, the positive aspects for each individual element in the Smith and Sainfort⁷ work system model will be examined separately to highlight the critical improvements. However, the most effective strategy is to approach these improvements as a global process to simultaneously improve many factors to produce a well balanced job.

Organizational support

Organizations must recognize the importance of a proper implementation strategy when new technology is brought into the workplace. Employee participation is an essential aspect of successful technology implementation^{43, 60, 62, 73}.

First-line supervisors are a critical link between the computer technology, organizational structure and employees' perceptions of working conditions⁶⁹. Non-supportive supervisors produce increased stress. Supportive supervisors can serve as buffers that "protect" employees from "hassles" that come from organizational or technological problems. This support serves to limit the negative perceptions that employees have about their work, particularly when new computer technology is introduced.

In addition supervisors can provide social support when employees are feeling stressed, which has been shown to be helpful in reducing stress reactions⁷⁴.

Loss of job security is a critical problem for computer workers⁶⁹. It is essential for organizations to alleviate worker fears of job loss by providing support, training in new skills and assurances of employment stability. Training has the added benefit of enhancing employee self-esteem, and reinforces the employees' confidence in employment stability and their value to the company.

Job content

There are three main aspects of job content that are of specific relevance in computer work; these are task complexity, employee skill use and career growth. In some respects, these are all related to the concept of developing the skills of employees. The primary means for enhancing job content is to increase the extent of skill use in performing job tasks. This typically means enlarging the scope of job tasks (increasing variety), as well as enriching the elements of each specific task (more complexity). Enlarging the number of tasks increases the repertoire of skills needed for successful performance, and also increases the number of decisions made by the employee in defining task sequences and activities. This can be achieved by "cross-training" employees to be able to carry out several tasks in a work group, rather than one, repetitive task. Increased variety reduces the psychological "boredom" that comes from repetitive work. However, there is no guarantee that enlargement alone will lead to increased skill use, unless the new tasks require different skills.

The next step is to increase the complexity of the tasks. This means increasing the amount of thinking and decision making. This can be achieved by combining simple tasks into sets of related activities that have to be coordinated, or by adding mental requirements that take additional knowledge and cognitive skills.

There are some instances when computerized technology is implemented when the new task activities have greater mental requirements than previous tasks, and these requirements may exceed the current knowledge and skills of the employees. When this happens, these new cognitive demands can cause psychological stress. To reduce this stress, employees need additional training so that they have the added knowledge and skills necessary to perform the tasks.

Job control

An aspect of job design that has a powerful psychosocial influence is the amount of control an employee has over job tasks and decision making^{75, 76}. Employees can be given autonomy in the methods and procedures they use in completing their tasks. In addition, groups of employees can self-manage several inter-related tasks. The group can decide who will perform particular tasks, the scheduling of tasks, coordination of tasks and production standards to meet company goals. Such teamwork promotes group control and a cooperative spirit. Finally, employees can participate in structured activities that provide input to management about employee opinions or quality improvement suggestions. This can be accomplished through quality improvement programs or quality of working life surveys.

Workload

A significant concern for employees when computer automation occurs is that their workload often increases¹⁰. These increases occur because a primary purpose of automation is to enhance the quantity and quality of work output. Computers can assist employees to work faster and more effectively, but we must ensure that in making employees more productive, they are not overworked, or put under too much work pressure. Reasonable production standards, or work output requirements, help to protect employees from excessive workload. The techniques of work methods analysis and time and motion analysis can be useful in establishing the proper workload.

Socialization

Computerized tasks often have high concentration demands which diminish the amount of social interaction during work⁶⁹.

This can lead to social isolation. To counter this, there should be structured opportunities for socialization. Such socialization provides social support which is an essential modifier of adverse psychological disturbances^{74, 77}.

Proper workstation ergonomics

It is important to recognize that poor ergonomic conditions can lead to psychosocial problems for computer users^{15, 78}. Thus, for holistic job design, there is also the need for proper ergonomic conditions^{2, 79, 80}. Smith and Cohen⁸⁰ provide guidelines for proper computer workstation design.

Finding the Proper Balance in Computer Work Design

In any redesign process there are “trade-offs” which require us to think about how to get the best “balance” that will have the greatest positive benefit for employee health and productivity at the most reasonable cost⁷. There are many factors that can produce adverse psychosocial conditions that lead to stress. Each of these factors is inter-related, so making modifications to a single factor may not provide an overall benefit if concomitant changes are not made in other factors to get a total work system balance. There are two aspects of “balancing” computer workplace design that need to be addressed. These are (1) the balance of the total system, and (2) compensatory balance.

System balance

System balance is based on the idea that a job is more than the sum of the individual components of the work system. It is the way in which the system components relate to each other that determines the potential for the system to produce positive results. If an organization concentrates solely on the technological component of the system, then there is an “imbalance” because the personal and psychosocial factors are neglected. Thus, job improvements must take account of the entire work system impact. The Smith and Sainfort⁷ “balance” model of the work system can do this by evaluating the relationships between job demands, job design factors, and stress for all elements in the work system. This then leads to potential solutions that accommodate the system elements in a complimentary fashion.

Compensatory balance

The second type of balance is “compensatory” in nature. It is seldom possible to eliminate all psychosocial factors that cause job stress, because it may be impossible to change

inherent aspects of job tasks. The essence of compensatory balance is to reduce psychological stress by making changes in aspects of work that can be positively changed to help improve the overall psychosocial environment of the job. While this does not remove those negative aspects that cannot be changed, it enhances the overall job situation. We all recognize that the optimal job design strategy would be achieved by providing all of those characteristics of each work element that meet recognized criteria for physical loads, work cycles, job content, cognitive requirements, job control, career development and socialization, and that provide for individual physiological and psychological needs. This design strategy eliminates all sources of stress that pertain to the individual. However, in reality, such an entire job redesign is unlikely, and it is unusual to "customize" redesign for each employee. So, the alternative strategy is to enhance positive work elements to compensate for poor work elements for all employees. This provides a balance for the psychosocial stress by moderating the influence of the negative factors.

Summary

There are several aspects of the design of computerized work that can influence the psychosocial stress and health of employees. Research has shown that the organizational methods used to implement new technology, extent of employees' control, task content, work pressures, career opportunities, job security, quality of environmental and ergonomic considerations, supervisory support, socialization at work, and many other work design issues all affect employee psychological and physical well-being. Interventions for controlling the potential adverse effects of new technology need to examine organizational issues, task characteristics, technology design, environmental design and individual employee characteristics for a total systems approach to achieve the best possible results for stress reduction and health enhancement. Using the concept of "balance" in job and organizational design can lead to successful, holistic solutions.

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References

- 1) OTA (1985) Automation of America's offices. Office of Technology Assessment, Congress of the United States, Washington DC.
- 2) Smith MJ, Carayon P (1995) New technology, automation and implementation strategies. *Int J Hum Factors Manufacturing* **5**, 99–116.
- 3) Cooper CL, Marshall J (1976) Occupational sources of stress: a review of the literature relating to coronary heart disease and mental ill health. *J Occup Psychol* **49**, 11–28.
- 4) Karasek R (1979) Job demands, job decision latitude, and mental strain: implications for job redesign. *Admin Sci Q* **24**, 295–308.
- 5) Smith MJ, Cohen BG, Stammerjohn LW, Happ A (1981) An investigation of health complaints and job stress in video display operations. *Hum Factors* **23**, 387–400.
- 6) Smith MJ (1987) Occupational stress. In: *Handbook of human factors*. ed. by Salvendy G, 844–860, John Wiley and Sons, New York.
- 7) Smith MJ, Sainfort PC (1989) A balance theory of job design for stress reduction. *Intl J Ind Ergon* **4**, 67–79.
- 8) Grandjean E, Vigliani E (1980) *Ergonomic aspects of visual display terminals*. Taylor and Francis, London.
- 9) Dainoff MJ (1982) Occupational stress factors in visual display terminal (computer) operation: a review of empirical research. *Behav Information Technol* **1**, 141–76.
- 10) Smith MJ (1987a) Mental and physical strain at computer workstations. *Behav Information Technol* **6**, 243–55.
- 11) Bergqvist U, Knave B, Voss M, Wibom R (1992) A longitudinal study of VDT work and health. *Int J Hum-Comput Interact* **4**, 197–219.
- 12) Grieco A, Molteni G, Occhipinti E, Piccoli B (1995) *Work with display units 94*. Elsevier Science Publishers, Amsterdam.
- 13) Gunnarsson E, Ostberg O (1977) Physical and emotional job environment in a terminal-based data system. National Institute of Occupational Health, Stockholm.
- 14) Sainfort PA (1990) Job design predictors of stress in automated offices. *Behav Information Technol* **9**, 3–16.
- 15) Smith MJ, Carayon P (1996) Work organization, stress and cumulative trauma disorders. In: *Beyond biomechanics: psychosocial aspects of cumulative*

- trauma disorders. eds. by Moon S, Sauter S, 23–42, Taylor and Francis, London.
- 16) Selye H (1956) *The stress of life*. McGraw-Hill, New York.
 - 17) Lazarus RS (1974) Psychological stress and coping in adaptation and illness. *Int J Psychiatry Med* **5**, 321–33.
 - 18) Lazarus RS (1977) Cognitive and coping processes in emotion. In: *Stress and coping*. eds. by Monatand A, Lazarus R, 145–158, Columbia University Press, New York.
 - 19) Levi L (1972) *Stress and distress in response to psychosocial stimuli*. Pergamon Press, New York.
 - 20) Smith MJ, Cohen BGF, Stammerjohn LW, Lalich N (1980) Video display operator stress. In: *Ergonomic aspects of visual display terminals*. eds. by Grandjean E, Vigliani E, 201–210, Taylor and Francis, London.
 - 21) Elias R, Cail F, Tisserand M, Christman M (1980) Investigations in operators working with CRT display terminals: relationships between task content and psychophysiological alterations. In: *Ergonomic aspects of visual display terminals*. eds. by Grandjean E, Vigliani E, 211–218, Taylor and Francis, London.
 - 22) Ghiringhelli L (1980) Collection of subjective opinions on use of VDUs. In: *Ergonomic aspects of visual display terminals*. eds. by Grandjean E, Vigliani E, 227–232, Taylor and Francis, London.
 - 23) Sauter SL, Gottlieb MS, Jones KC, Dodson VN, Rohrer KM (1983) Job and health implications of computer use: initial results of the Wisconsin-NIOSH study. *Commun ACM* **26**, 284–94.
 - 24) Starr SJ, Thompson CR, Shute SJ (1982) Effects of video display terminals on telephone operators. *Hum Factors* **24**, 699–711.
 - 25) Starr SJ, Shute SJ, Thompson CR (1985) Relating posture to discomfort in computer use. *J Occup Med* **27**, 269–71.
 - 26) Starr SJ (1984) Effects of video display terminals in a business office. *Hum Factors* **26**, 347–56.
 - 27) Bradley G (1989) *Computers and the psychosocial work environment*. Taylor and Francis, London.
 - 28) Westlander G (1994) The full-time computer operator as a working person: musculoskeletal work discomfort and life situation. *Int J Hum-Comput Interact* **6**, 339–64.
 - 29) Aronsson G (1989) Changed qualification demands in computer-mediated work. *Appl Psychol Int Rev* **38**, 57–71.
 - 30) Stellman JM, Klitzman S, Gordon GC, Snow BR (1985) Air quality and ergonomics in the office: survey results and methodologic issues. *Am Ind Hyg Assoc J* **46**, 286–93.
 - 31) Carayon-Sainfort P (1992) The use of computers in offices: impact on task characteristics and worker stress. *Int J Hum-Comput Interact* **4**, 245–61.
 - 32) Yamada F (1998) Frontal midline theta rhythm and eyeblinking activity during a VDT task and a video game: useful tools for psychophysiology in ergonomics. *Ergonomics* **41**, 678.
 - 33) Rau R (1996) Psychophysiological assessment of human reliability in a simulated complex system. *Biol Psychol* **42**, 287–300.
 - 34) Yamamoto S, Matsuoka S (1996) Study of mental stress with event-related potential (contingent negative variation). In: *Recent advances in event-related brain potential research*. eds. by Ogura C, Koga Y, Shimokochi M, 886–890, Elsevier Science, Tokyo.
 - 35) Schleifer LM, Amick III BC (1989) System response time and method of pay: stress effects in computer-based tasks. *Int J Hum-Comput Interact* **1**, 23–39.
 - 36) Schleifer LM, Okogbaa OG (1990) System response time and method of pay: cardiovascular stress effects in computer-based tasks. *Ergonomics* **33**, 1495–509.
 - 37) Schleifer LM, Ley R (1994) End-tidal PCO₂ as an index of psychophysiological activity during VDT data-entry work and relaxation. *Ergonomics* **37**, 245–54.
 - 38) Carayon-Sainfort P, Smith MJ (1991) Impact of computer system performance on task characteristics and employee stress. In: *Human aspects in computing: design and use of interactive systems and work with terminals*. ed. by Bullinger HJ, 195–199, Elsevier Science Publishers, Amsterdam.
 - 39) Van den Berg PT, Schalk R (1997) Type A behavior, well-being, work overload, and role-related stress in information work. *J Soc Behav Personal* **12**, 175–87.
 - 40) Hudiburg RA, Necessary JR (1996) Coping with computer-stress. *J Educ Comput Res* **15**, 113–24.
 - 41) Hudiburg RA, Necessary JR (1996) Psychology of computer use: XXXV. differences in computer users' stress and self-concept in college personnel and students. *Psychol Rep* **78**, 931–7.
 - 42) Asakura T, Fujigaki Y (1993) The impact of computer technology on job characteristics and worker health. In: *Human computer interaction: applications and case studies 19A*. eds. by Smith MJ, Salvendy G, 982–987, Elsevier, New York.

- 43) Lindström K (1991) Well-being and computer-mediated work of various occupational groups in banking and insurance. *Int J Hum-Comput Interact* **3**, 339–61.
- 44) Polanyi MFD, Cole DC, Beaton DE, Chung J, Wells R, Abdoell M, Beech-Hawley L, Ferrier SE, Mondloch MV, Shields SA, Smith JM, Shannon HS (1997) Upper limb work-related musculoskeletal disorders among newspaper employees: cross-sectional survey results. *Am J Ind Med* **32**, 620.
- 45) Bernard B, Sauter S, Fine L, Petersen M, Hales T (1994) Job task and psychosocial risk factors for work-related musculoskeletal disorders among newspaper employees. *Scand J Work Environ Health* **20**, 417–26.
- 46) Hales TR, Sauter SL, Petersen MR, Fine LJ, Putz-Anderson V, Schleifer LR, Ochs TT, Bernard BP (1994) Musculoskeletal disorders among visual display terminal users in a telecommunications company. *Ergonomics* **37**, 1603–21.
- 47) Smith MJ, Conway FT, Cahill J, LeGrande D (1996) Psychosocial aspects of cumulative trauma, In: *Human factors in organizational design and management*. ed. by Brown O, 297–302, Elsevier, Amsterdam.
- 48) Conway FT, Smith MJ, Cahill J, LeGrande D (1996) Psychological mood state of tension and musculoskeletal pain. In: *Human factors in organizational design and management*. ed. by Brown O, 303–308, Elsevier, Amsterdam.
- 49) Carayon P, Yang C-L, Lim S-Y (1995) Examining the relationship between job design and employee strain over time in a sample of office employees. *Ergonomics* **38**, 1199–211.
- 50) Fujigaki Y (1996) Time series investigation of job-events and depression in computer software engineers. *Ind Health* **34**, 71.
- 51) Fujigaki Y, Mori K (1997) Longitudinal study of work stress among information system professionals. *Int J Hum-Comput Interact* **9**, 369–81.
- 52) Lindström K, Leino T, Seitsamo J, Ilkka T (1997) A longitudinal study of work characteristics and health complaints among insurance employees in VDT work. *Int J Hum-Comput Interact* **9**, 343.
- 53) Tanaka T, Fukumoto T, Yamamoto S, Noro K (1988) The effects of VDT work on urinary excretion of catecholamines. *Ergonomics* **31**, 1753–63.
- 54) Tanaka T, Yamamoto S (1992) VDT work affects urinary excretion of catecholamines in the young. *Int J Hum Comput Interact* **4**, 173–81.
- 55) Murata K, Araki S, Kawakami N, Saito Y, Hino E (1991) Central-nervous-system effects and visual fatigue in VDT workers. *Int Arch Occup Environ Health* **63**, 109–13.
- 56) Trimmel M, Huber R (1998) After-effects of human-computer interaction indicated by P300 of the event-related brain potential. *Ergonomics* **41**, 649.
- 57) Majchrzak A, Cotton J (1988) A longitudinal study of adjustment to technological change: from mass to computer-automated batch production. *J Occup Psychol* **61**, 43–66.
- 58) Huuhtanen P, Leino T (1992) The impact of new technology by occupation and age on work in financial firms: a 2-year follow-up. *Int J Hum-Comput Interact* **4**, 123–42.
- 59) Korunka C, Weiss A, Huemer K-H, Karetta B (1995) The effect of new technologies on job satisfaction and psychosomatic complaints. *Appl Psychol Int Rev* **44**, 123–42.
- 60) Korunka C, Huemer KH, Litschauer B, Karetta B, Kafka-Lutzow A (1996) Working with new technologies-hormone excretion as indicator for sustained arousal *Biol Psychol* **42**, 39–52.
- 61) Korunka C, Weiss A, Karetta B (1993) Effects of new technologies with special regard for the implementation process per se. *J Org Behav* **14**, 331–48.
- 62) Karsh B-T (1997) An examination of employee participation during new technology implementation. In: *Proceedings of the human factors and ergonomics society 41st annual meeting*, 767–771, Human Factors and Ergonomics Society, Santa Monica.
- 63) Korunka C, Weiss A, Zauchner S (1997) An interview study of “continuous” implementations of information technology. *Behav Information Technol* **16**, 3–16.
- 64) Korunka C, Zauchner A, Weiss A (1997) New information technologies, job profiles, and external workload as predictors of subjectively experienced stress and dissatisfaction at work. *Int J Hum-Comput Interact* **9**, 407–24.
- 65) Wastell DG, Newman M (1996) Stress, control and computer system design: a psychophysiological field study. *Behav Information Technol* **15**, 183–92.
- 66) Boucsein W, Thum M (1997) Design of work/rest schedules for computer work based on psychophysiological recovery measures. *Int J Ind Ergon* **20**, 51.
- 67) Hovmark S, Wollberg EF, Nordqvist S (1996) A longitudinal study of health complaints in professional computer work: effects of computer-aided design. *Int*

- J Hum-Comput Interact **8**, 401–20.
- 68) Carayon P (1993) Effect of electronic performance monitoring on job design and worker stress: review of the literature and conceptual model. *Hum Factors* **35**, 385–95.
- 69) Smith MJ, Carayon P, Sanders KJ, Lim S-Y, LeGrande D (1992) Electronic performance monitoring, job design and worker stress. *Appl Ergon* **23**, 17–27.
- 70) Carayon P (1994) Effects of electronic performance monitoring on job design and employee stress: results of two studies. *Int J Hum-Comput Interact* **6**, 177–90.
- 71) Schleifer LM, Galinsky, TL, Pan CS (1996) Mood disturbances and musculoskeletal discomfort: effects of electronic performance monitoring under different levels of VDT data-entry performance. *Int J Hum-Comput Interact* **8**, 369–84.
- 72) Hendrick H (1986) Macroergonomics: a conceptual model for integrating human factors with organizational design. In: *Human factors in organizational design and management*. eds. by Brown O, Hendrick H, 467–477, Elsevier Science, Amsterdam.
- 73) Haims M, Carayon P (1996) Implementation of an in-house participatory ergonomic program: A case study in a public service organization. In: *Human factors in organizational design and management*. eds. by Brown O, Hendrick H, 175–180, Elsevier Science, Amsterdam.
- 74) Yang C-L, Carayon P (1995) Effect of job demands and social support on employee stress: a study of computer users. *Behav Information Technol* **14**, 32–40.
- 75) Sainfort PC (1991) Stress, job control and other job elements: a study of office workers. *Int J Ind Ergon* **7**, 11–23.
- 76) Carayon P (1995) Chronic effects of job control, work pressure and supervisor social support on office worker stress. In: *Organizational risk factors for job stress*. eds. by Sauter, SL, Murphy LR, 357–370, American Psychological Association, Washington DC.
- 77) Carayon P (1993) Job design and job stress in office workers. *Ergonomics* **36**, 463–77.
- 78) Smith MJ (1984) Health issues in computer work. In: *Visual display terminals*. eds. by Bennet J, Case D, Sandlin J, Smith MJ, 193–228, Prentice Hall, New Jersey.
- 79) Smith MJ, Carayon P, Eberts R, Salvendy G (1992) Human-computer interaction. In: *Handbook of industrial engineering*. ed. by Salvendy G, 1107–1144, John Wiley and Sons, New York.
- 80) Smith MJ, Cohen W (1997) Design of computer terminal workstations. In: *Handbook of human factors and ergonomics*. ed. by Salvendy G, 1637–1688, John Wiley and Sons, New York.
- 81) Smith MJ (1997) Psychosocial aspects of working with video display terminals (VDTs) and employee physical and mental health. *Ergonomics* **40**, 1002–15.
- 82) Smith MJ, Karsh B-T, Moro FB (1998) Review of research on interventions to control musculoskeletal disorders. National Academy of Science workshop on musculoskeletal injuries, Washington DC, August 20–21.