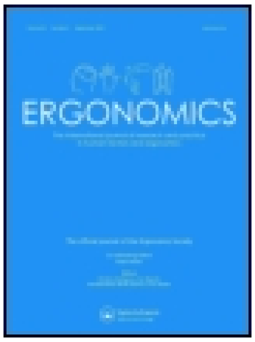

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The effects of computer interface design on human postural dynamics

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The main objective of this study was to examine the effects of human–computer interface design on *postural dynamics*, i.e., changes in working postures and postural discomfort exhibited by operators of the computer-based remote bar coding (RBC) system. In addition, the effects of different work/rest schedules on postural dynamics were evaluated. Twelve subjects participated in the laboratory experiment, which consisted of twelve scenarios utilizing two cognitive task requirement factors, i.e., (1) information presentation mode, defined through the letter image preview on the computer screen (none or one preview image); and (2) the information processing mode, defined through the specific keying method (*key all characters or key 5 digits only*). The third experimental factor was the work/rest schedule (50 min work/10 min break, 2 h of work/15 min break, or flexible schedule). The results showed that requirements of human–computer interface design significantly affected the operators' postural dynamics. It was concluded that not only the physical, organizational, or psychosocial work environment characteristics, but also the cognitive task characteristics are important for assessment of postural effects in the VDT work. The relationship between interface design, mental workload and postural dynamics should be carefully considered in future studies aimed at optimizing the human–computer data entry tasks.

1. Introduction

Many studies reported adverse health effects when working with video display terminals (VDTs), including visual problems and musculoskeletal discomfort and injury (Smith *et al.* 1981, Dainoff 1982, Colombini *et al.* 1986, Floru and Cail 1987, Grandjean 1987). Visual problems reported among VDT users include eyestrain, burning/itching eyes, blurred or double vision, deterioration of visual acuity, and headaches (Grandjean 1984a, b). An important survey of health problems experienced by the VDT operators (Evans 1985), which was based on 3819 self-report questionnaires, showed as the most frequently reported symptoms: eyestrain (70·3%), painful/stiff neck or shoulders (52·4%), and back pain (42·9%). Fatigue and irritated eyes were reported by 57·7% and 43·8% of respondents, respectively. Blurred vision was experienced by 33·7% of the operators, while burning eyes by 28·9% of the workers. The back, neck, shoulders, and wrists are often the most frequent musculoskeletal complaints. A recent survey of 512 VDT operators reported by Bodek (1990), revealed the following health complaints: painful neck and shoulders (reported by 64% of the operators), back pain (52%), pain in arms and legs (28%), and swollen muscles and joints (12%). Hand problems, like hand cramps (14·1%), stiff/sore wrists (10·6%), and loss of feeling in fingers and wrists (5%) were also reported (Evans 1985). An excellent review of both mental and physical strain issues when working at VDT workstations was presented by Smith (1987; 1992a).

Daily exposure to VDT work is another contributory risk factor of reported health problems. For both men and women, the health effects increase in incidence and in severity with the numbers of hours worked. In the study by Evans (1985), the reports of painful/stiff neck or shoulders increased from 48% at 1–2 h of work to 65% at 6–8 h of work, while the incidence of back pain increased from 37·1% at 1–2 h of work to 55·8% at 6–8 h of work. Eyestrain was experienced by 63·4% and 80·4% of the operators after 1–2 h and 6–8 h of work with VDT, respectively.

Many of the musculoskeletal problems in VDT work are associated with poor sitting postures (Corlett *et al.* 1986). The contributory risk factors also include equipment design (design of workstations and chairs), and job design. According to Grandjean (1987), *a VDT as such does not cause physical discomfort, it is the way it is used that is responsible for constrained postures and the ensuing troubles.* As reported by Evans (1985), only 50·8% of the 3819 VDT operators who participated in his study were using adjustable screen tables, 64·2% of them were able to adjust the keyboard height, while 70·8% of the operators could adjust the height of the chair. Recently, Dainoff (1990) performed a controlled study with experimental data-entry simulation tasks, and concluded that a group of the same VDT operators working under near optimal ergonomic conditions exhibited higher levels of performance and lower levels of postural discomfort, comparing to working under sub-optimal conditions.

2. Postural strain at VDT workstations

Several studies showed that VDT work is associated with high risk of shoulder–neck disorders, which is mainly due to the effect of static tension in the shoulder–neck muscles (Hagberg and Wegman 1987, Winkel and Oxenburgh 1990). A positive correlation between the incidence of shoulder–neck complaints and the duration of VDT work was also reported (Bergqvist 1984). As early as 1984, Oxenburgh (1984) observed that the shoulder-neck complaints also occur at 'good' (i.e., ergonomically correct) VDT workstations. Recently, Winkel and Oxenburgh (1990) suggested that it is the lack of physical variation which becomes a major problem in the use of VDT workstations. Winkel (1985) suggested that modest increase in leg activity performed while sitting may be sufficient to reduce the perceived leg/foot discomfort. Postural rigidity of data-entry operators was discussed by Thompson (1990), who observed that regular breaks do little to alleviate physical strain of the VDT operators, while carefully designed exercise breaks included in the workday's schedule can effectively reduce the musculoskeletal strain and discomfort due to postural rigidity.

The present state of knowledge suggests several cause–effect relationships between VDT design characteristics, body posture, and perceived postural comfort of the operators (Hunting *et al.* 1981, Grandjean 1984b, Andersson 1987, Bodek 1990). For example, stiffness and pains in the neck increase when there is an increasing degree of forward bending (inclination) of the head. Marek and Noworol (1986) reported significant increase in head inclination with time during the 2 h work shift. Chaffin and Andersson (1984) concluded that the inclination angle of the head should not exceed 20–30° for any prolonged period of time. Grandjean *et al.* (1983) proposed the backward leaning posture as optimal for the VDT operators. Backward inclination of the upper trunk and use of back support reduces strain on the spinal discs and back muscles, while use of a foot support reduces the strain on the legs. The optimum conditions concerning spine disc pressures and muscular activity are given for backrest inclination of 100° to 115°. According to Grandjean (1987), the VDT operators prefer trunk inclination of 100° and 110°. Also, 80% of the office workers rest their forearms or wrists if a proper support is available, while 50% rest their forearms and wrists on the desk surface in front of the keyboard when no appropriate support is provided. Aaras *et al.* (1990) recommended that when working with a VDT one should minimize the angles of flexion/abduction of the upper arm in the shoulder joints. Grandjean (1981) pointed out the importance of using the backrests and generated a study which reported that office workers were in contact with the chair backrest for about 42% of the time.

Maeda *et al.* (1980) reported that when keying with speeds between 8000–12 000 strokes/hour the postures of VDT operators were rather constant over the 5–6 h of work studied. Frequent postural changes may be an indication that the operator is trying to alleviate the effect of local postural discomfort. Cantoni *et al.* (1984) examined postures of the VDT operators working at new and old workstations in a switchboard control room. The postural change was defined as alteration of even one variable describing the postural sequence which included trunk and legs. They reported a significant decrease in the number of postural changes per hour when changing from the old to the new VDT workstation. It was suggested that the observed increase in postural fixity could be alleviated by introducing a 15 min break every 2 h of work.

3. Objectives

The interaction with VDT should allow for dynamic muscle work in order to prevent constrained postures that increase static muscular loading and the risk of related incidence of musculoskeletal disorders among the VDT operators (Grieco 1986). Aaras *et al.* (1990) concluded that dynamic muscle work which reflects the operators variation in posture and postural movements may be beneficial to the musculoskeletal system. The majority of previous studies of postural problems experienced when working with VDTs emphasized physical design of hardware including adjustability of computer workstations, task workload, task variability and duration, work practices and work organization, and environmental and psychosocial factors (Smith 1992b). However, as discussed by Wærsted *et al.* (1991), it also is possible that increasing mental requirements of the computer data entry tasks may have an adverse effect on the extent of muscular loading of the human operator.

The increased muscular tension due to a greater task difficulty was reported by experimental psychologists as early as the 1930s (Davis 1938, Shaw and Kline 1947, Eason and White 1961). The effects of higher perceptual or computational task requirements and associated levels of mental loading on human muscular activity and related postural strain and discomfort were studied, among others, by Fussler-Pfohl *et al.* (1984), Svebak (1988) and Westgaard and Bjørklund (1987). Edwards (1988) suggested that high levels of mental workload may contribute to the increased muscular tension, and, therefore, can be considered as the potential risk factor for musculoskeletal disorders.

Recently, Wærsted *et al.* (1991) studied the effects of different levels of task complexity on the extent of activity in the shoulder muscle for computer-based tasks performed under conditions of similar levels of postural strain. The subjects were exposed to two tasks utilizing a graphical display and an alphanumerical text, i.e. (1) a simple visual reaction time task, and (2) a more complex, two-choice visual reaction time task, and were asked to push a button as soon as the visual stimulus appeared on the computer screen. The authors concluded that the observed differences in shoulder muscle tension between the two tasks were the effect of an increased mental effort due to higher computational demands of the more complex task. It should be noted that the duration of experimental time in the study by Wærsted *et al.* (1991) was limited to about 10–15 min per task, and that both VDT tasks, although of different complexity, were abstract-based and relatively simple visual reaction choice tasks.

The present research project aimed to examine possible relationships between the interface design requirements and operator's posture in a computer data entry task under controlled laboratory conditions. It was hypothesized that different levels of mental load due to specific human–computer interface design characteristics, including the mode of information presentation (display design) and information processing (keying requirements), affect operator posture and perceived postural comfort at work. Specifically, the main objective of this study was to investigate the effects, if any, of different cognitive requirements of the computer data-entry task, defined in terms of information presentation and processing, i.e. the visual image preview and keying method, respectively, on postural dynamics, defined in terms of changes in working postures and perceived postural discomfort, exhibited by operators of the computer-based remote bar coding (RBC) system. In addition, this study investigated the effects of different work/rest schedules on patterns of postural changes and discomfort over time. Both cognitive and physical aspects of working with VDT workstations were studied simultaneously in order to determine the potential relationships between them.

4. The remote bar coding task

4.1. *Task requirements*

In the computer-based, remote bar coding (RBC) task the operators enter address information from digitized images of mail pieces which, for various reasons, are not machine-readable. Typically, the operator enters the ZIP and the plus 4 add-on code, if available, on the letters. If the plus 4 add-on code is not available, the operator enters the information on the address line which, in the most typical case, includes the digits of the number, the street name, and any pre- and post-directionals. The computer system then compares this information with all addresses in an address database. If a match occurs, the mail piece is sprayed with a bar code containing the final destination information. If a match does not occur, the mail piece is rejected and further processing is needed.

The above tasks exhibit certain similarities and differences when compared to the traditional computer data entry tasks. The remote bar coding is the repetitive, data entry task that utilizes a computer keyboard. However, instead of the to-be-entered data provided on paper document, data are presented on the computer screen, resulting in less head movements, but possibly higher eyestrain due to continuous monitoring of the VDT. Furthermore, mail pieces do not have to be manipulated by hand but appear on the computer screen, while data on paper sheets would have to be manipulated by hand. The human factors of the encoding process need to be considered so that the keying task, including visual perception of the letters, information processing, and the keying response, is as efficient and comfortable as possible.

4.2. *Design of keying method*

Preliminary analysis of the RBC system was aimed at identifying and testing several information processing modes, as defined by different keying methods. There are two overall possibilities for keying method: i.e. (1) the heads-down keying, where the operator inputs the address line as it appears on the mail piece; or (2) the extraction coding, where the operator only keys part of the address line and the computer fills in the rest of the line by comparing the extraction code to letter address possibilities in the database. Therefore, these two methods, namely keying the first five characters (*key 5 digits*), and keying the entire address line (*key all characters*), were used in the study.

4.3. *Design of information display*

One of the unresolved issues was the mode of information presentation to the operator, i.e., whether or not to include a preview of the next mail images on the computer screen. In a preview condition, the operator would be able to see the display, both the current mail piece image and the next mail piece image. In this situation, the operator could obtain information about the next mail piece while keying the current mail piece.

Information processing can be divided into three stages: perception, cognitive, and motor response (Card *et al.* 1983). Research on dual tasks, summarized by Wickens' (1984) model of human information processing, indicated that some of the processing of the information could be performed in parallel. In particular, a perception/cognition stage could be performed in parallel with the response to the previous information. Using the information processing of mail pieces as an example, mail piece #2 could be perceived and cognitively processed (to identity and decide on the entries from the address line) at the same time that the motor responses on the keyboard were being made to mail piece #1. The *preview condition* was included in the human–computer interface design in order to take advantage of this parallel processing because two mail piece images were always on the screen. Parallel processing could not be done in the *no preview condition* because the next mail image would not appear on the screen until the response to the previous mail image was completed.

4.4. *Mail piece images*

The task was designed to be as realistic as possible. The mail piece images were collected from a northern Virginia location, and the distribution of destinations reflected what could be expected for this site or comparable sites. Consequently, a majority of mail pieces were addressed to sites in close proximity to northern Virginia. Since most mail pieces have local destinations, the first three digits of the zip code (called the CSF code) would be very similar. Following practices, coding is made easier by providing single keys (called SCF keys) so that all three digits of the SCF can be entered at once. Of course, for further destinations, an SCF key would not be available.

Because the coding task realism was preserved, the operators had to decide which technique to use for entering an address. All operators used the plus 4 add-on, if available, although very few mail pieces had this number. The operators were instructed to use the SCF keys, if possible. In analysing the results, the data were categorized according to the technique used.

4.5. *Design of work/rest schedule*

Another important task requirements issue was the work/break schedule. Currently in the United States Postal Service (USPS), some operators perform the task for 2 h and then take a break for 15 min. This is different from German postal systems, for example, where operators may perform the task for 50 min and then take 10 min breaks. Another possible schedule is for the operators to work until tired. Wennberg and Voss (1987) reported slight decrease in quantitative performance (number of letters coded per minute) and decrease in qualitative performance (higher error rate) during work without morning and afternoon breaks as compared to work with breaks for the video encoding operators in Sweden. There is also a possibility that interactions may occur between the different conditions. As an example, the work/break scheduling may interact with the number of images on the screen because previewing the next image may be more tiring than not previewing the next image.

5. Methods and procedures

5.1. *Subjects*

Twelve operators (nine females and three males) were hired through a local employment service. The average age of the subjects was 22·0 years old (SD = 2·4). The average weight and height values of the subjects were 62·7 kg (11·7 kg) and 166·0 cm (11·2 cm), respectively. The keyboard experience in computer data entry tasks ranged from 0 to 6 years, with an average of 1·9 years (SD = 2·3). The selection criterion for participating in the study was a minimum typing speed of 40 (correct) words per minute. In order to screen the potential operators for any musculoskeletal problems they may have had in the past, a modified version of the standard Nordic questionnaire reported by Kuorinka *et al.* (1987) was used. Only those operators with no previous history of musculoskeletal symptoms were used in the study.

5.2. *Experimental design*

In order to minimize the cost of the study and to develop realistic postal testing conditions, a limited number of experimental conditions were designed. The experiment consisted of twelve scenarios in which the three independent variables, i.e. (1) of keying method (*key all digits* or *key 5 digits only*); (2) image preview (none or one); and (3) work/break schedule (50 min/10 min, 2 h/15 min, of flexible schedule) were combined. A three factorial (2 × 2 × 3) design with replication was used (see table 1).

The three work/rest schedules were as follows: (1) 50 min keying and 10 min break; (2) 2 h of keying and 15 min break; and (3) key until tired (flexible work). The schedules were set so the operators in each condition keyed for 240 min; including those in the flexible condition. Selection of the work/rest schedule was based on research literature for the ergonomics of the automated data entry tasks and existing practices in the industry. For example, the *German Remote Video Encoding System* allows for a 50 min keying period and 10 min break. The keying methodologies consisted of keying the first five characters of the street address or keying all the street address. The operators were instructed to type in any pre- or post-directionals and also the first character of the suffix unless it was a 'street'.

Table 1. Design of experiment for analysis of posture and postural changes.

Sequence number	1	2	3	4	5	6	7	8	9	10	11	12
Work/rest schedule	1	2	3	1	2	3	1	2	3	1	2	3
Keying method	1	1	1	2	2	2	1	1	1	2	2	2
Preview condition	1	1	1	1	1	1	2	2	2	2	2	2
Work/rest schedule	1—50 min work/10 min break 2—120 min work/15 min break 3—flexible schedule (up to 240 min of work)											
Keying method	1—key all letter address characters 2—key 5 digits only											
Preview condition	1—no preview (one image) 2—preview present (two images)											

5.3. *Equipment*

Each of the three workstations used in the study consisted of a separate CPU with hard disk, keyboard, and a video display terminal (VDT). The Gateway 2000 computers were PC/AT compatible, based upon the 80386 chip with a processing speed of 25 MHz. Each had a separate 150 Mb hard disk. The VDTs were Princeton Graphics LM301 monitors with a resolution of 1664 × 1200. The keyboards were standard QWERTY detachable keyboards with a numeric keypad and 13 function keys. The function keys were as follows. On the top row there were a total of eight SCF function keys, a reject key, help key, a clear key (clears the whole address), and an exit key (for quitting the task). When pressed, the SCF function keys would display the first 3 digits of the postal ZIP code. Eight of the most useful SCF keys were provided. The reject key could be used to reject mail pieces in which the image was unreadable. Situated in the QWERTY keyboard were also a general delivery key, a 'PO' Box key, and a rural delivery key. The correct key was situated on the editing keypad.

The VDT workstations used in the experiments were compatible with accepted ergonomic standards (ANSI/HFS-100 1988). Subjects worked with fully adjustable computer workstations, including chair, keyboard support, screen support and footrest. The working environment was controlled so that the operators were comfortable. An air conditioner and thermometer were used to control the temperature of the room and maintain a comfortable 72–75°. The ambient lighting was between 300 and 500 lux. Background music was used to mask any noises outside the office.

5.4. *Screen layout*

The layout of the screen was designed in accordance with USPS practices and specifications. Figure 1 illustrates the screen layout for the non-preview conditions (scenarios 1 through 6). The image of the mail piece appears at the top of the screen. The bottom half of the screen are the fields for the address entry. The top field is for the ZIP and the plus 4 add-on. The second line is where the city and state information appears as soon as the ZIP information is entered. The third line is for entry of the street information. Figure 2 shows a picture of the screen layout for the preview conditions (scenarios 7 through 12). The layout is exactly the same except that two images appear on the upper half of the screen. The bottom image is the current image being processed and the top image is the next image to be processed.

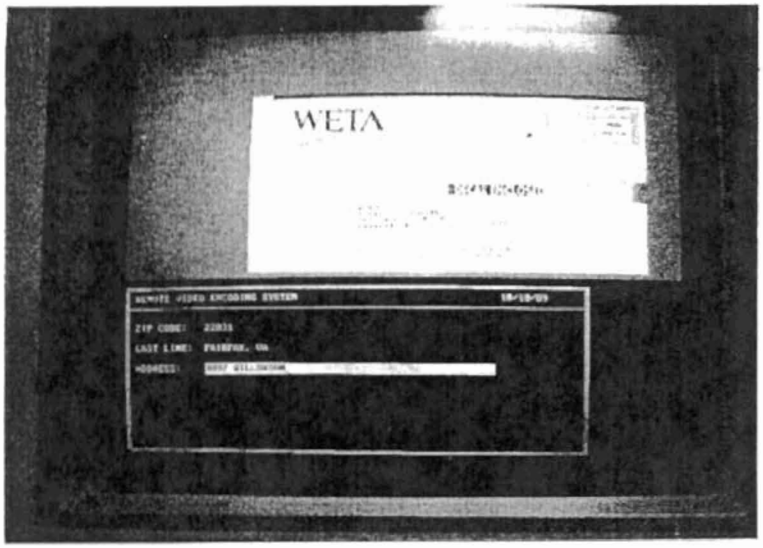

Figure 1. Picture of the screen layout for the non-preview conditions (scenarios 1–6).

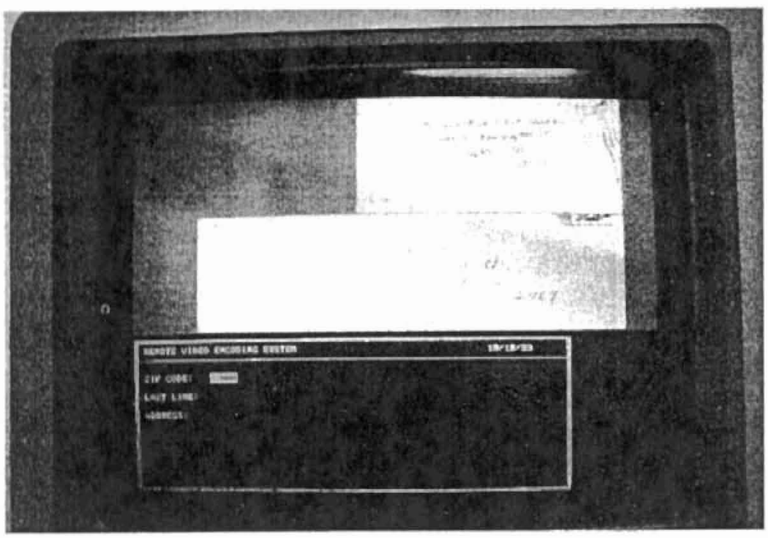

Figure 2. Picture of the screen layout for the preview conditions (scenarios 7–12).

5.5. *Operator training*

Following the structured individual training, the operators practiced on their own. During this period, the experimenters were available to answer questions addressed by the operators. Each operator practiced each keying method for one hour. A 15 min break was given to the operators after the first hour of practice. The order of training for each keying method was reversed for each new set of three operators. For example, the first set of three operators were initially trained on the *key all characters* method, and then on the *key 5 digits* method. The second set of operators were first trained on the *key 5 digits* method and then on the *key all characters* method.

6. Experimental procedures

6.1. *Operator testing schedule*

Each person worked in all 12 combinations of conditions (called scenarios or sequences) shown in table 1, each of the 12 taking 4 h on a separate day. The subjects were paid for 5 h to include the time for questionnaires and breaks. Half the subjects worked in the mornings (08:00–13:00) and half in the afternoons (13:00–18:00). Only three people could work simultaneously due to restrictions of space and equipment; so the first morning and afternoon crews were tested on all scenarios, and then the remaining six subjects were also divided into morning and afternoon crews and tested the same way.

All subjects performed mail coding tasks in all 12 scenarios with the first group of six operators completing all scenarios before the next group of six began the experiment. To reduce any practice effects, the operators sequenced through the scenarios in a random order with the following restriction. To limit any disruption which may occur for operators leaving the room for different break times, the three operators present for any session were all assigned the same work/break schedule. For the same session, though, the different operators may have been in different scenarios using different keying methodologies and different preview conditions.

6.2. *Assessment of body postures*

To assess the body postures, video recordings were made of subjects. To record each of the 12 subjects in all 12 sequences (scenarios) shown in table 1 would have been impractical, so only two subjects were recorded in each scenario (each subject paired with another subject), resulting in a total of 24 treatments. This allowed analysis as a three-way factorial design with replication. For each of these treatments, three 10 min video-recording sessions were made (an additional time-on-task factor nested within subjects), i.e., at the beginning, middle, and end of the work period, according to the schedule given in table 2. In total, 72 10 min video sessions were recorded.

The video camera was placed on the preferred hand side of the operator and positioned at the operator's elbow height. Each operator was informed about the purpose of videotaping and signed a short consent form. The list of body angles and postural changes of interest with respect to posture recording and analysis are shown in table 3. The body angles (degrees) were analysed at 1 min intervals. The values for body movements represent a total number of movements for a specific body part over a period of 10 min. The values for foot and back support represent the proportion of time these were in use during the 10 min period.

For comparison purpose, the body angles were defined after Maeda *et al.* (1980), Hunting *et al.* (1981), and Grandjean *et al.* (1983). The neck/head angle was defined after Kilbom *et al.* (1986) based on the VIRA method of postural analysis. The upper arm flexion was an angle formed by the line crossing the estimated centres of elbow and shoulder joints and horizontal line. The upper trunk flexion angle was formed between the horizontal line and the line crossing the estimated centres of the shoulder and hip joints. The measured body angles are illustrated in figure 3.

6.3. *Assessment of postural discomfort*

The epidemiological research on musculoskeletal disorders nowadays often relies on methods based on subjective feelings of pain and discomfort. Recently, Laubli *et al.* (1991) proved that illustrated questionnaires asking for the rate of symptom

Table 2. Experimental design for collecting postural dynamics data using video recording technique.

Work/rest schedule	Time (min)		
#1 Work time	0–50	60–110* 120–170	180–230
Data collection time #1	40–50	140–150	220–230
#2 Work time	0–120	135–255	
Data collection time #2	40–50	190–200	245–255
#3 Work time	Up to 240 min of work with spontaneous breaks		
Data collection time #3	40–50	140–150	220–230

Table 3. Elements of posture recorded and analysed.

1. Neck/head flexion angle [degrees]
2. Number of neck/head movements* (up–down)
3. Upper arm angle [degrees]
4. Upper trunk flexion [degrees]
5. Number of upper body movements* (forward–backward)
6. Number of lower leg movements* (forward–backward)
7. Use of lower back support**
8. Use of forearm support**
9. Use of foot support**

* Total number of postural changes during the 10 min period.
** Proportion of time used during the 10 min period.

Table 4. Experimental design for postural discomfort data collection.

Work/rest schedule	Time of data collection		
	Time #1	Time #2	Time #3
1	before experiment	110–120	after experiment
2	before experiment	120–135	after experiment
3	before experiment	during 2nd break	after experiment

occurrence (like the *Questionnaire on Occupational Cervicobrachial Disorders* by the Japanese Committee on Occupational Cervicobrachial Disorders or the *Standardized Nordic Questionnaire for the Analysis of Musculoskeletal Symptoms*) are reliable and valid methods to measure the musculoskeletal discomfort. Also, since musculoskeletal discomfort is mainly a localized symptom, it must be studied separately for neck/shoulder, back/low back, right arm/hand, and left arm/hand.

Winkel and Oxenburgh (1990) used the modified analogue-visual 10 cm scale first proposed by Freyd (1923), with two extremes of local body discomfort, i.e., '*not at all*' and '*very much—cannot work*'. In this study, a modified method of postural discomfort assessment proposed by Corlett and Bishop (1976) was used. As pointed out by Corlett (1990), such quantified discomfort can be used as a linear scale. The scale is then divided at the 1/2 points to give an effective 14-point scale to be used for subsequent statistical analysis.

Assessment of the operator's postural discomfort was performed before the work started, immediately after each work period (during the break), and immediately after

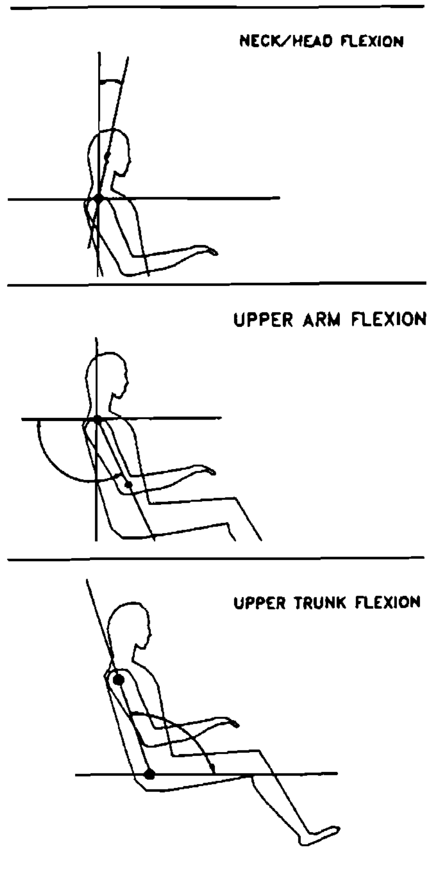

Figure 3. Measured body angles.

the task was completed (see table 4). First, the subject was asked to indicate the overall body discomfort using a seven-point scale with 'no discomfort' and 'extremely uncomfortable', marked at its left- and right-hand ends, respectively. Next, the operator was asked to choose (based on the diagram of body areas) which body area was giving her/him the greatest discomfort, and indicate on the corresponding scale the level of such discomfort. The subject was then asked to identify the next area with the highest level of discomfort, and so on.

7. Results and discussion

7.1. *Background data about operator keying performance*

As background data about the remote letter coding task, the information about operator keying performance was collected. Table 5 shows the average keystroke time, in ms, across the different conditions (keying method, preview or no preview, and work/break schedule). Keystroke time was measured by taking the interval between the first keystroke and the last keystroke for an image, then dividing by the number of keystrokes. On average, the operators performed the street name keystrokes faster by 55 ms in the *key all characters* condition than in the *key 5 digits* condition,

Table 5. Average keystroke times (ms) for each condition.

Variable	Street name	SCF ZIP	ZIP 5-digit	ZIP plus-4
Keying method				
Key all characters	295	312	494	778
Key 5 digits only	350	313	510	783
Preview condition				
No preview	323	425	518	737
Image preview	322	200	487	824
Work/rest schedule				
50/10 schedule	317	313	505	773
120/15 schedule	326	314	499	793
Flexible schedule	324	311	504	775

Table 6. Summary of significant results for MANOVA analyses of body posture and postural changes.

Body position and changes ($n = 72$)	Work/rest schedule F	Work/rest schedule p	Keying method F	Keying method p	Preview condition F	Preview condition p	Time effect F	Time effect p
Neck/head flexion	3·9	0·02						
Neck/head movements	10·8	0·0001	4·4	0·04			3·5	0·05
Right elbow flexion					4·4	0·04		
Upper trunk flexion	4·6	0·01						
Upper body movements			22·9	0·0001				
Lower leg movements			17·5	0·0001			4·2	0·02
Use of lower back support	27·6	0·0001			11·6	0·001		
Use of foot support	4·0	0·02						

$F(1, 132) = 9{\cdot}59$, $p < 0{\cdot}01$. The keystroke times in the other conditions for the street name were all quite similar so that no appreciable difference occurred. For the ZIP entry when the operators used the SCF function key and then the last two digits of the ZIP for input, average keystroke time was much faster for the *preview condition* when compared to the *no preview condition*, $F(1, 132) = 104{\cdot}53$, $p < 0{\cdot}0001$. Furthermore, the keystrokes with preview condition were more than twice as fast (average of 425 ms compared to 200 ms). This pointed out to an advantage of the preview condition, because the operators were obviously previewing the mail piece, storing the ZIP in memory, and then entering the information as fast as possible.

The advantage of the preview was not apparent, however, for the ZIP entries. When the operators entered the 5-digit ZIP code, little advantage was found in the *preview condition* (487 ms) when compared to the *no preview condition* (518 ms), $F(1, 132) = 1{\cdot}17$. When the operators entered a plus 4 add-on, the advantage was in favour of the *no preview condition* (737 ms) instead of the *preview condition* (824 ms), $F(1, 132) = 7{\cdot}81$, $p < 0{\cdot}01$. Apparently, the operators did not have the ability to store the add-on in memory along with the 5-digit ZIP, and having to look at the screen again to find the plus 4 was disruptive. The differences for the keying method and the work/break scheduling were not significant.

7.2. *Operators' posture and postural changes*
The collected experimental data for observed postures and postural changes were analysed statistically using the multivariate analysis of variance (MANOVA), and the Newman–Keuls test to compare the differences between means. The values of perceived postural discomfort were subject to a paired-sample *t*-test procedure.

7.2.1. *The effect of work/rest schedule*: The summary of results for the significant factors identified by the MANOVA analysis are shown in tables 6–7. The work/break schedule significantly affected the neck/head flexion angle, upper trunk flexion angle, and frequency of use of the low back support and use of foot support response variables. The neck/head flexion was the lowest (mean = 30·2°) for the flexible work/break schedule, and the highest (mean = 36·5°) for the 50 min work/10 min break schedule. The 50/10 min schedule also resulted in the most frequent movements of the head (up and down) during the 10 min periods studied (mean = 98·7), while the flexible schedule induced the lowest number of neck/head movements (mean = 70·9). The operators tended to use their foot support more often during the 50/10 min and 120/15 h work schedules (63% and 67% of the time), than during the flexible schedule (33% of the time).

Finally, analysis of the effects of time on operators postural dynamics revealed a significant increase in the number of neck/head and lower leg movements with the progression of work, with the maximum values toward the end of working sessions in both cases (see table 7).

7.2.2. *The effect of keying method*: The keying method had a significant effect on the frequency of operators' neck/head, the upper body (torso) and lower leg movements. The instruction to *key all characters* resulted in more movements of the neck/head and less movements of the upper body and lower legs, than the instruction to *key 5 digits only*.

7.2.3. *The effect of preview condition*: The preview condition resulted in smaller upper arm flexion (mean = 108·2°), indicating more relaxed operator's posture (Grandjean *et al.* 1983, Aaras *et al.* 1990) (see figure 3 for angle definition), as compared to the no preview condition (mean = 115·6°). Both angles are similar to those that are preferred by the VDT users population. Grandjean (1987) reported an average upper arm flexion of 113°. Preview condition also significantly affected the use of the low back support. On average, the subjects used back support 34·7% of the time. When working with no preview of the next image, the backrest was used 27% of the time. The backrest utilization increased to almost 50% of the time with the image preview, indicating more relaxed posture at work with the preview condition. For comparison, Grandjean (1987) reported that office workers were in contact with the backrest for about 42% of the time.

7.3. *Postural discomfort*
7.3.1. *The effect of work duration and work/rest schedule*: The results of postural discomfort analysis (see figure 4) revealed significant effects of data collection time on all reported discomfort scores. The operators exhibited greater postural discomfort on

Table 7. Main effects for the observed body postures and postural changes over time.

Dependent variable	Independent variable		Mean*	SD	Range	*n*
Neck/head flexion	Work/rest schedule					
	1	a	36·5	7·8	20–50	24
	2	b	31·5	10·4	10–45	24
	3	b	30·2	11·7	5–50	24
Neck/head movements	1	a	98·7	19·0	48–125	24
	2	b	75·9	27·6	12–119	24
	3	c	70·9	40·0	15–156	24
	Keying method					
	1	a	87·3	28·7	15–121	36
	2	b	76·4	34·7	12–156	36
Wrist discomfort	1	a	8·52	1·4	4–13	36
	2	b	7·80	1·8	3–12	36
Upper arm angle	Preview condition					
	1	a	115·6	17·0	90–140	36
	2	b	108·2	15·8	60–130	36
Upper trunk flexion	Work/rest schedule					
	1	a	107·1	17·4	80–145	24
	2	b	119·6	12·6	90–140	24
	3	b	116·7	19·6	70–140	24
Upper body movements	Keying method					
	1	a	8·4	3·94	2–15	36
	2	b	15·3	7·36	3–33	36
Lower leg movements	1	a	10·5	32·3	0–140	36
	2	b	15·8	26·3	55–150	36
Use of lower back support	Work/rest schedule					
	1	a	0·37	0·21	0–1	24
	2	b	0·67	0·42	0–1	24
	3	c	0·15	0·08	0–1	24
	Preview condition					
	1	a	0·27	0·41	0–1	36
	2	b	0·47	0·51	0–1	36
Use of foot support	Work/rest schedule					
	1	a	0·62	0·49	0–1	24
	2	a	0·67	0·48	0–1	24
	3	b	0·33	0·48	0–1	24
Neck/head movements	Time effects					
	1	a	70·5	29·8	12–113	24
	2	b	82·0	32·3	16–121	24
	3	c	93·0	31·3	20–156	24
Lower leg movements	1	a	10·7	3·7	6–22	24
	2	ab	13·0	4·7	4–24	24
	3	b	15·8	8·7	5–38	24

* Different letters indicate significant differences between means at $p < 0.05$.

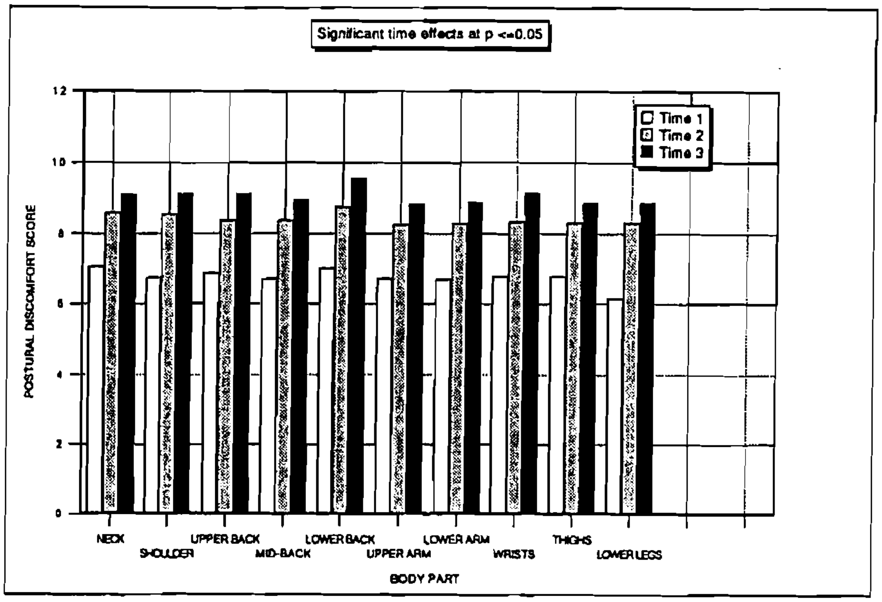

Figure 4. Postural discomfort ratings.

all the body parts as the 4 h session progressed. The evaluation taken before the experiment showed that the operators exhibited relatively low levels of postural discomfort, while the evaluations taken immediately after the experiment showed significantly higher ($p < 0{\cdot}01$) levels of perceived discomfort ratings across all measurements. These results are consistent with other studies. For example, Wærsted *et al.* (1991) reported that more than half of the subjects in their study of shoulder muscle tension induced by two VDT-based tasks of different complexity exhibited higher discomforts in the neck and/or shoulder regions at the end of the work period.

7.3.2. *The effect of keying method*: The keying method used by the operators had a significant effect on the perceived discomfort of the wrists (table 8). The instruction to *key all characters* resulted in higher wrist discomfort than the instruction *key 5 digits only*. As discussed above, the subjects were making more keystrokes at a faster rate in the *key all characters* condition when compared to the *key 5 digits only* condition (see table 5). Therefore, it could be expected that this situation would cause more wrist discomfort.

As illustrated in table 8, there was also a large number of significant interaction effects, mainly for the two factors (work/rest schedule*preview condition) on the perceived postural comfort of the body. For example, it should be noted that under *image preview* condition, the low back discomfort was significantly lower with *keying 5 digits only* method comparing to the *keying all characters* mode.

7.3.3. *The effects of preview condition and work/rest schedule*: No significant differences occurred in terms of postural discomfort across the two preview conditions or across the three work/break schedules. A number of interactions occurred, however, between the preview condition and work/break schedule, and between the keying

Table 8. Significant interactions between interface design, work/rest schedule and perceived postural comfort.

Discomfort	Interaction effects	Means*		
Overall	Preview condition**	Work/rest schedule		
		1	2	3
	No image preview	8·6 a	8·8 a	8·2 a
	Image preview	7·8 b	7·2 b	8·6 a
Low back	Preview condition**	Work/rest schedule		
		1	2	3
	No image preview	8·4 a	8·5 a	7·8 a
	Image preview	7·9 a	7·2 b	8·8 b
		Preview condition		
Low back	Keying method*	No preview		Image preview
	Key all characters	8·8 a		9·6 a
	Key 5 digits only	8·5 a		8·0 b
Upper arm	Preview condition**	Work/rest schedule		
		1	2	3
	No image preview	8·4 a	8·6 a	8·0 a
	Image preview	7·6 b	7·2 b	8·8 b
Wrist	Preview condition**	Work/rest schedule		
		1	2	3
	No image preview	8·4 a	8·8 a	7·6 a
	Image preview	7·6 b	7·8 b	8·8 b
Wrist		Keying method		
	Work/rest schedule*	Key all		Key 5 digits
	1 hr + break	9·20 a		9·28 a
	2 hrs + break	9·50 ab		9·26 a
	Flexible	8·40 b		9·20 a

* Different letters indicate significant differences between means at $p < 0.05$.
** Analysis of differences between means for preview condition.

method and work/break schedule (see table 8). In the preview condition with two images on the screen, the operators reported the most discomfort with flexible schedule, while in the *no preview condition* with one letter image, they exhibited more discomfort on the 50 min work/10 min rest (50/10) and the 2 h work/15 min break (120/15) schedules. An explanation for these results could be that under the *flexible schedule condition*, the subjects 'pushed themselves' to work as long as they possibly could before taking a break. Combining this strategy to finish the work with the extra cognitive processing required to perform the *preview condition* in parallel, could have been the cause of the extra discomfort seen for the *preview/flexible work* schedule combination. The summary of identified patterns of postural dynamics as a function of interface design and work/rest schedule is depicted in table 9.

7.4. *Operator behaviour under condition of flexible work/break schedule*

It should be also noted that under the *flexible work/break* schedule, no guidelines were given to the operators regarding how to take their breaks. Table 10 contains the information about the work times and break times in the flexible work/rest condition. The average keying time before a break was 116 min. After the first break,

Table 9. Patterns of postural dynamics as a function of computer interface design characteristics and different work/rest schedules.

Keying method	
Key all characters	Key 5 digits only
More neck/head movements ⊕ (more stressful posture)	Less neck/head movements ⊖ (more relaxed posture)
Higher wrist discomfort ⊕	Lower wrist discomfort ⊖
Less upper body and legs movements ⊖ (more relaxed posture)	More upper body and legs movements ⊕ (more stressful posture)
Image preview condition	
No image preview	Image preview
Greater upper arm flexion ⊕ (more stressful posture)	Smaller upper arm flexion ⊖ (more relaxed posture)
Less backrest use ⊖	More backrest use ⊕
Higher discomfort with 50/10 and 120/15 work/rest schedules ⊕	Lower discomfort with flexible work/rest schedule ⊖

⊕—Indicates higher values.
⊖—Indicates lower values.

Table 10. Distribution of work times before breaks and the break times (min).

	First period		Second period		Third period		Fourth period	
Time descriptor	work	break	work	break	work	break	work	break
Average time	116	7	95	6	28	9	57	4
Maximum	240	17	197	18	120	16	86	4
Minimum	43	1	47	1	30	3	38	4
n	48	41	41	24	24	11	11	1

Table 11. Main effects for the analysis of body postures and postural changes at the end of experimental sessions.

Dependent variable	Independent variable	Mean*	SD	Range	*n*
Upper body movements	Keying method				
	1	a 9·25	4·09	3–15	12
	2	b 19·67	7·41	7–33	12
Lower leg movements	Keying method				
	1	a 12·17	6·56	5–25	12
	2	b 19·42	9·34	5–38	12
Use of lower back support	Work/rest schedule				
	1	a 0·37	0·52	0–1	8
	2	b 0·65	0·52	0–1	8
	3	c 0·17	0·14	0–1	8
Use of foot support	Work/rest schedule				
	1	a 0·75	0·28	0–1	8
	2	b 0·62	0·23	0–1	8
	3	c 0·25	0·12	0–1	8

* Different letters indicate significant differences between means at $p < 0·05$.

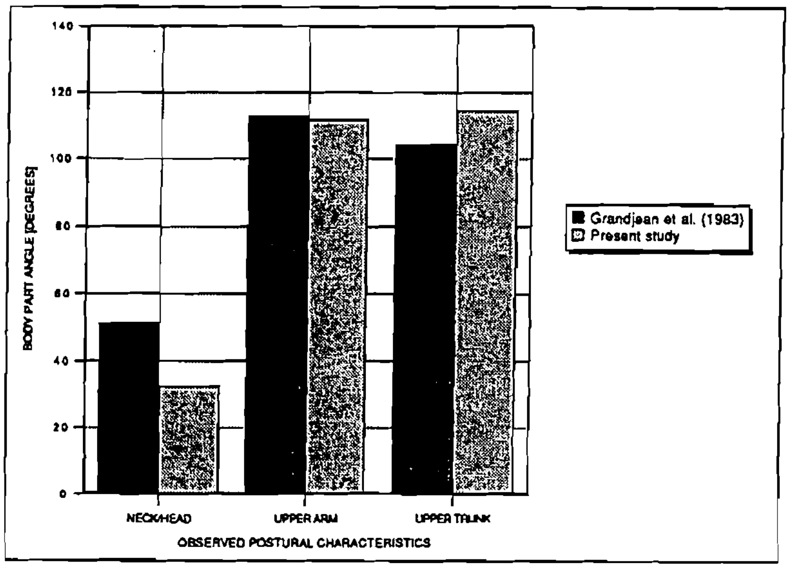

Figure 5. Observed postures of the RBCS operators.

the duration of keying before fatigue forced the operators to take a break decreased to 95 min. However, seven of the operators keyed 4 h without a break at one time or another. The length of time on the break was, on the average, 7 min for the first break and 6 min for the second break. The majority of operators preferred to key in three work periods or less. The operators indicated in interviews on the final day that their fatigue changed daily, and on some days they felt like working longer hours but on other days they did not.

7.5. *The effect of time on postural dynamics*

Finally, due to the significant effect of time on the perceived postural discomfort, the effects of experimental variables on postural dynamics for the last data collection time were also investigated. The results (see table 11) confirm the earlier observations regarding the effect of work/rest schedule on the frequency of use of lower back support and foot support, the effect of keying method on frequency of upper body and leg movements, and the effect of preview condition on frequency of use of back support.

7.6. *Preferred postures of the RBC operators*

As illustrated in figure 5, the observed values for neck/head flexion, upper arm flexion, and upper trunk flexion were similar to those preferred by 59 VDT operators in a study reported by Grandjean (1987). It should be noted, however, that upper trunk angle (back inclination) for the posture assumed by RBC operators was on average by 10° greater than the one exhibited by the VDT operators. In addition, there was greater variability in the preferred posture of the trunk in this study as compared to the study by Grandjean (1987). It was also observed that RBC operators working with the 120/15 and flexible work schedules had smaller neck/head inclination angle (about 30°) than the 36° angle observed for 50/10 work schedule.

It should be noted that forward head flexion in this study was on average about 33°, but was also accompanied by high discomfort to the neck area, and significant increase in neck/head movements (head posture changes) with time over the 2 h work shift. As pointed out by Andersson (1987), the stress on the cervical spine results mainly from the position of the head, which is influenced by visual requirements and posture of the trunk. When forward neck flexion exceeds 30° under condition of an upright trunk posture, rapid fatigue of the cervical extensor muscles was observed (Chaffin 1973). However, Grandjean *et al.* (1983), reported much larger head inclination with mean value of 51° preferred by the VDT operators. This could be due to the fact that the subject in the above study also exhibited posterior trunk inclination (Andersson 1987).

7.7. *Postural dynamics at different work/rest schedules*

In terms of the work/break schedule, the operators in this study used back support and foot support, and did lean backward more often under the 120/15 schedule (see table 9). Also, the observed neck/head angle for this work/break schedule was smaller compared to the 50/10 schedule, but did not differ from the flexible work/break schedule. The 120/15 schedule also resulted in the greatest angles of upper trunk (backward) inclination of the subjects, suggesting a more relaxed posture than the one for the 50/10 schedule, but not different from the flexible schedule. Grandjean (1987) suggested that for postures associated with preferred settings of the VDT workstations, the operators moved only occasionally and tended to maintain their postures over time. The results of this study showed that the 120/15 schedule produced significantly less neck/head movements than the 50/10 schedule, but more than the flexible schedule. However, there were also more changes in the posture of lower legs for the 120/15 schedule than for 50/10 schedule.

As discussed by Maeda *et al.* (1980) and Cantoni *et al.* (1984), frequent postural changes are an indication that the operator is trying to alleviate the effect of local postural discomfort. In the present study, *keying 5 digits only* method resulted in significantly less changes in the posture of the neck/head, but more changes in the postures of upper body and lower legs than observed under the *key all characters* methods (see table 9). This trade-off indicates that subjects were able to adjust the postures of the upper body and legs in order to alleviate discomfort when the requirements for keying were lower (*key 5 digits only*). These observations are also consistent with the findings by Grieco (1986) who argued that postural immobility in sedentary work can be a risk factor for musculoskeletal strain. In view of the fact that the number of movements of the neck/head increased with time of work (see table 6), the lesser number of neck/head changes indicates more relaxed neck/head posture with the *key 5 digits only* method. Similar findings were reported by the French researcher Laville (1968), who found an increasing number of head movements and corresponding higher levels of relative muscular loading with progression of time, measured during 15 min intervals over a two-hour period.

Finally, it should be emphasized that in order to better understand the effects of computer interface design of human postural dynamics, a holistic view may be needed that links postural changes in different parts of the body, and considers these in relation to corresponding ratings of perceived discomfort over time (Kuorinka 1993).

8. Conclusions

This controlled laboratory study, like that reported by Dainoff (1990), was conducted under near optimal ergonomic conditions with respect to VDT workstation design, and organizational and environmental conditions. The RBC operators were working with fully adjustable computer workstations, including chair, keyboard support, screen support, and footrest. Furthermore, the operators were all well trained in the mail coding tasks. In general, the sitting postures were found to be similar to those reported in the literature. The study revealed significant effects of cognitive RBC task requirements on postural dynamics, i.e., the effect of keying method on frequency of the upper body and leg movements, and the effect of image preview condition on the frequency of use of back support. In addition, there was also a significant effect on the work/rest schedule of the frequency of use of lower back support and use of foot support.

This study showed that observed postural dynamics, defined in terms of operator's body posture, postural changes and perceived postural discomfort at work were affected by the cognitive task requirements, defined in terms of information presentation (letter image preview condition), and information processing (*keying method*), and by the organizational factor of work/rest schedule. The results of the present study confirm the notion that not only the physical, organizational or psychosocial work environment characteristics, but also the cognitive task requirements are important for comprehensive assessment of postural dynamics in VDT work. The above results are in agreement with the earlier studies by Fussler-Pfohl *et al.* (1984), Westgaard and Bjørklund (1987), and Wærsted *et al.* (1991), reporting an increasing muscular activation in cognitively more elaborate computer-based tasks. Results of the present study also support the hypothesis that high mental workload can be a risk factor for musculoskeletal disorders (Edwards 1988). The relationship between cognitive task requirements, such as the mode of information presentation and the mode of information processing, the related mental workload, and human postural dynamics, should be carefully considered in future studies aimed at optimizing computer-based data entry tasks.

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