

Ergonomic Aspects of Portable Personal Computers with Flat Panel Displays (PC-FPDs): Evaluation of Posture, Muscle Activities, Discomfort and Performance

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Abstract: The advent of compact and lightweight portable personal computers has offered its users mobility. Various sizes of PC-FPDs can now be seen in the occupational setting as an alternative to the desktop computers. However, the increasing popularity of this relatively new technology may not be without any accompanying problems. The present study was designed to evaluate the use of PC-FPDs in terms of postural changes, muscle load, subjective complaints and performance of the subjects. Ten subjects, 5 males and 5 females, were asked to perform a text-entry task for 5 minutes using each of the 5 types of personal computers—1 desktop and 4 PC-FPDs of various sizes. Results showed that the posture assumed by the subjects while using the PC-FPDs was significantly more constrained than that assumed during work with the desktop computer. Viewing and neck angles progressively lowered and the trunk became more forward inclined. The EMG results also revealed that the activities of the neck extensor in PC-FPDs were significantly higher than in the desktop computers. Trends of increasing discomfort and difficulty of keying with the use of smaller PC-FPDs were noted. Performance was significantly lower for smaller PC-FPDs. This study shows that PC-FPDs have ergonomic attributes different from the desktop computer. An ergonomic guideline specific for PC-FPDs users is needed to prevent the surge in health disorders previously seen among desktop computer users.

Key words: Flat panel display (FPD), Posture, Electromyography (EMG), Discomfort, Performance

Introduction

The popularity of the portable personal computers with flat panel displays (PC-FPDs) in recent years is reflected by the year-on-year increase in its production. More than 3 million PC-FPD units have been marketed in Japan for 1997 only¹⁾. This volume makes up 40% of the total computer output for the same year. Correspondingly, the presence of the PC-FPDs in offices and industries has been growing. The advantages this new technology offer may account for this growth. From the ecological viewpoint, attributes of less energy consumption, smaller space requirement and lower noise generation make the PC-FPDs preferable over

the desktop computers. The added feature of mobility because of the compact and lightweight built has also enhanced the appeal of the PC-FPDs.

Various sizes of portable FPDs can now be seen in the occupational setting as an alternative to the desktop computers. However, the increasing popularity of the portable computers may not be without any accompanying problems, particularly to the health of its users. Villanueva *et al.*²⁾ compared the assumed posture of operators while using a PC-FPD and a desktop computer. Neck flexion was noted to be more pronounced while using the smaller visual display unit (VDU). Chaffin³⁾ has shown that the rate of fatigue increases with a greater degree of downward head tilt affecting endurance to do work. Some authors have also attributed the incidence of pain in the cervical region to the

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Table 1. Characteristics of the computers used

Display type	Display size, diagonal (inches)	Keyboard size (cm × cm) ^a	Keyboard thickness (cm) [‡]	Keyboard inclination (deg)
CRT	17	28.3 × 9.3	2.6	8
FPD A	13.8	28.0 × 9.3	6.1	8
FPD B	10.4	25.1 × 8.7	1.8	0
FPD C	7.2	21.7 × 6.9	2.6	0
FPD D	6.1	8.7 × 5.9	2.3	0

^a without ten keys and function keys. [‡] measured from home keys.

increased head flexion. It is likely that the moment created by neck flexion, which must be resisted by neck muscle forces, contribute to the occurrence of pain⁴.

It is also foreseen that the consequent complaints and health disorders among its users may differ from those seen among desktop computer users due to the difference in dimensions and design. Another study had already shown that the subjective complaints of PC-FPD users differed from desktop users⁵. Thus, adapting the existing ergonomic guidelines for desktop computer use may not be sufficient to avert the emergence of health problems from the use of the PC-FPDs.

The present study was designed to evaluate the use of PC-FPDs from the ergonomic point of view. The study analyzed the postural differences among the different types of displays. Muscle activities, subjective complaints and display preference of the users were also evaluated. Results noted during operation of the PC-FPDs were compared with those noted while using a desktop.

Subjects and Method

Subjects

Ten subjects (5 male and 5 female) were asked to participate in this experimental study. Ages ranged from 22 to 54 years (mean: 33.6 ± 10.7 years). Mean height was 164.8 cm with standard deviation of 5.8 cm. All subjects were capable of performing text-entry tasks. The subjects had no complaints referable to the musculoskeletal and visual systems during the time the experiment was conducted.

Experimental workstation

Five visual display units, 1 desktop computer with cathode ray tube screen (the CRT) and 4 PC-FPDs, were used by the participants. The displays were set on top of a 70-cm height office desk⁶. The subjects were instructed, prior to working with each of the display units, to adjust the chair height until the forearms are parallel to the ground when

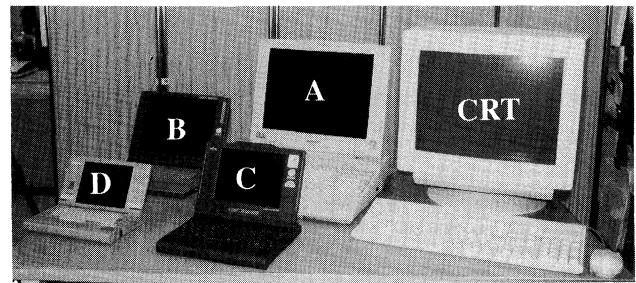


Fig. 1. The different display units used for the experiment: the desktop computer(CRT) and FPD A, B, C and D

the hands are poised over the home keys of the keyboard. Monitor tilt were adjusted to the subject's preferred settings. The subjects were also allowed to position the keyboard of the CRT and PC-FPDs relative to the table surface according to their preference. The specifications of the displays used are summarized in Table 1. Figure 1 shows the relative sizes of the display units used in the study.

The level of lighting in the experimental room was kept constant during the experimental period. Reflections and glares in the visual field were eliminated.

Task

The subjects were asked to perform a two-handed text-entry task using each of the display units. The text with 10.5 font size to be copied was on the left side of the split-screen. Typing was done on the right side of the split-screen. The subjects were instructed to work at their best speed. Correction of errors was allowed. A total of 8 texts were prepared for the experiment. The subjects were presented with a different text for each display unit. The order of text presentation was completely randomized.

Data measured

A. Posture analysis: The posture of the subjects while

using the different display units was monitored three-dimensionally using the Vicon system (Oxford Metrics Ltd., UK). The postural parameters were sampled at a rate of 60 Hz for 5 min. Only the measurements taken every 6 seconds were used for analysis.

Markers were placed on the subject and the display units to define the angles and distances to be measured. The 12 parameters evaluated included the following⁷:

1. Viewing angle: angle formed by the horizontal reference and the line between the eye and the middle of the screen
2. Neck angle: based on the Reid's line referenced to the horizontal line
3. Trunk inclination: defined by the line between the seventh cervical vertebra (C7) and the iliac crest referenced to the horizontal line
4. Thoracic bending: angle formed by C7, angulus inferior scapula and iliac crest
5. Shoulder rotation: angle formed by the line between the lateral epicondyle of the humerus and the styloid process of the ulna referenced to the horizontal line (Fig. 2a)
6. Shoulder flexion: angle defined by the acromion and lateral epicondyle of the humerus referenced to the horizontal line
7. Shoulder abduction: angle defined by the acromion and lateral epicondyle of the humerus referenced to the vertical line
8. Elbow angle: angle defined by the acromion, lateral epicondyle of the humerus and styloid process of the ulna
9. Elbow position relative to the table edge: distance of the lateral epicondyle of the humerus from the edge of the table
10. Ulnar deviation: angle formed by the 3rd metacarpophalangeal joint and midline of the wrist joint referenced to the horizontal line (Fig. 2b)
11. Wrist extension: angle defined by the 3rd metacarpophalangeal joint and midline of the wrist joint referenced to the horizontal line (Fig. 2c)
12. Viewing distance: distance between the lateral canthus of the left eye and the middle of the screen

B. Electromyography (EMG): The electromyographic activities of the neck extensor, trapezius pars descendens, deltoideus pars acromialis and extensor carpi ulnaris muscles on the left side of the body were monitored during the study. A portable EMG machine (MEGA ME3000P, Mega Electronics, Ltd., Finland) was used to collect the muscle activities. The averaged data were sampled at 1000 Hz and stored every 100 msec for 5 min.

The muscle activities were standardized as percentage of

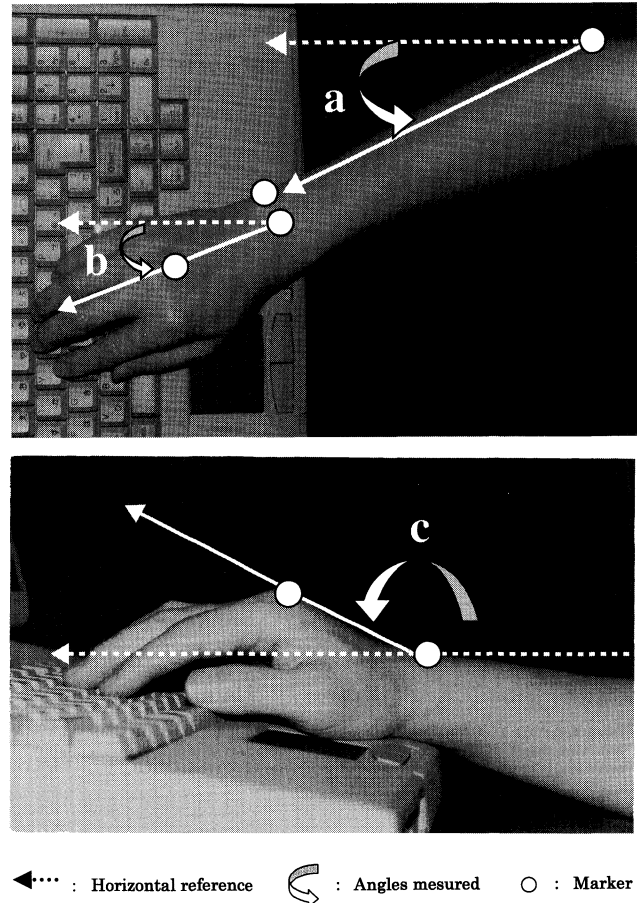


Fig. 2 The angle used to measure the degree of shoulder rotation (a), ulnar deviation (b) and wrist extension (c)

the maximum voluntary contraction (%MVC). The amplitude probability distribution frequency (APDF) curve of the standardized data was determined. The 10th and 50th percentiles (representing the static and mean components, respectively) of the APDF were used for analysis.

C. Discomfort survey: At the end of each segment of the experiment, the subjects were asked to accomplish a questionnaire using the 10-cm visual analog scale (VAS). Items in the questionnaire included questions on muscle and eye discomfort, intensity of discomfort and difficulty of keying. The displays were also ranked according to the preference of the subjects.

D. Performance monitoring: The performance of each subject was also monitored by counting the number of words typed within the duration of the experiment while using each of the display units. The number of errors was subtracted from the total words typed to arrive at a performance indicator.

Procedure

Each subject was asked to complete the entire experiment in 1 day by using all 5 display units while performing the text-entry task. The order of display use was completely randomized. The subjects were given 5 min for adaptation at each display unit. The following 5 min were allotted for data gathering. The subjects were asked to take 10-min rests in between display unit changes.

Statistical analysis

The experimental data were subjected to statistical analysis using repeated measures ANOVA. The results of repeated measures ANOVA were subjected to multiple comparison to determine significant differences in the parameters determined among the different display units. Statistical significance was set at $p < 0.05$.

Results

The monitor tilt settings favored by the subjects were significantly affected by the size of the display unit. The degree of backward tilting increased as the size of the VDU

decreased. The mean backward tilt positions for all FPDs were significantly greater than that for the CRT. The greatest backward tilt was seen while using the smallest FPD (Table 2). The ensuing monitor height was also lowest for FPD D.

The posture assumed by the subjects while using the FPDs was significantly different from that assumed during work with the CRT in 7 of the 12 parameters measured (Table 3). Constrained posture was more prominent when using the smaller FPDs (Fig. 3). The difference from the posture while at work with the CRT is greater for FPDs smaller than FPD A. Viewing and neck angles progressively lowered, and the trunk became more forward inclined as the display size decreased. Likewise, the viewing distance when using FPDs was shorter than when the CRT was used. The wrist was relatively more flexed only when using FPD B.

It is interesting to note, however, that the desk was used more effectively as forearm rest when the subjects were working with smaller FPDs as evidenced from the distance of the elbow from the table edge. Another positive effect of the use of the FPDs may be the greater inward rotation of the shoulders in comparison to the shoulder position while using the CRT.

The EMG results also showed that the activities of the neck extensor, deltoideus pars acromialis and extensor carpi ulnaris muscles were affected by the type of display used (Table 4). The static and median values of the EMG activities of the neck extensor muscles were significantly higher for all FPDs than for the CRT. Activities of the deltoideus pars acromialis muscle were elevated significantly only for FPDs A and B. The EMG activities of the extensor carpi ulnaris muscle were significantly higher than in the CRT for FPD B only. Comparison of the static and median activities of the trapezius muscle while using each of the 5 display units did not show any significant differences. The lowest

Table 2. Monitor tilt and height of the displays used

Display	Monitor tilt (degree) ^a	Monitor height (cm)
CRT	- 5.5 ± 3.0	96.0 ± 0.7
FPD A	- 22.2 ± 5.7*	92.9 ± 0.5*
FPD B	- 32.6 ± 4.8*	81.1 ± 0.5*
FPD C	- 37.3 ± 7.1*	80.2 ± 0.4*
FPD D	- 41.0 ± 6.3*	76.4 ± 0.4*

^anegative sign implies backward tilt. * significantly different from CRT value ($p < 0.05$).

Table 3. Postural parameters measured during work with different types of display^a

Parameter measured	Display type				
	CRT	A	B	C	D
Viewing angle (deg)	- 17.9 ± 3.1	- 23.5 ± 4.8*	- 36.9 ± 5.6*	- 39.6 ± 6.5*	- 45.3 ± 7.2*
Neck angle (deg)	- 13.8 ± 4.4	- 15.4 ± 5.9	- 19.6 ± 6.3	- 22.1 ± 7.4*	- 25.6 ± 7.7*
Trunk inclination (deg)	97.0 ± 10.1	95.4 ± 9.8	91.8 ± 10.0*	91.3 ± 11.8*	89.1 ± 8.5*
Shoulder rotation (deg)	28.6 ± 2.9	28.6 ± 5.2	31.8 ± 6.0*	34.9 ± 6.4*	36.8 ± 5.6*
Elbow position [‡] (cm)	16.2 ± 7.3	9.3 ± 6.5*	7.7 ± 5.5*	8.2 ± 6.1*	5.8 ± 5.2*
Wrist extension (deg)	152.0 ± 5.8	155.7 ± 3.2	158.5 ± 5.2*	153.9 ± 4.3	150.7 ± 7.0
Viewing distance (cm)	50.5 ± 8.7	49.3 ± 7.2	46.7 ± 8.0*	43.4 ± 7.1*	41.2 ± 6.5*

^aonly results significantly different from the CRT values are shown. [‡] elbow position relative to the edge of the table. * significantly different from values for CRT ($p < 0.05$).

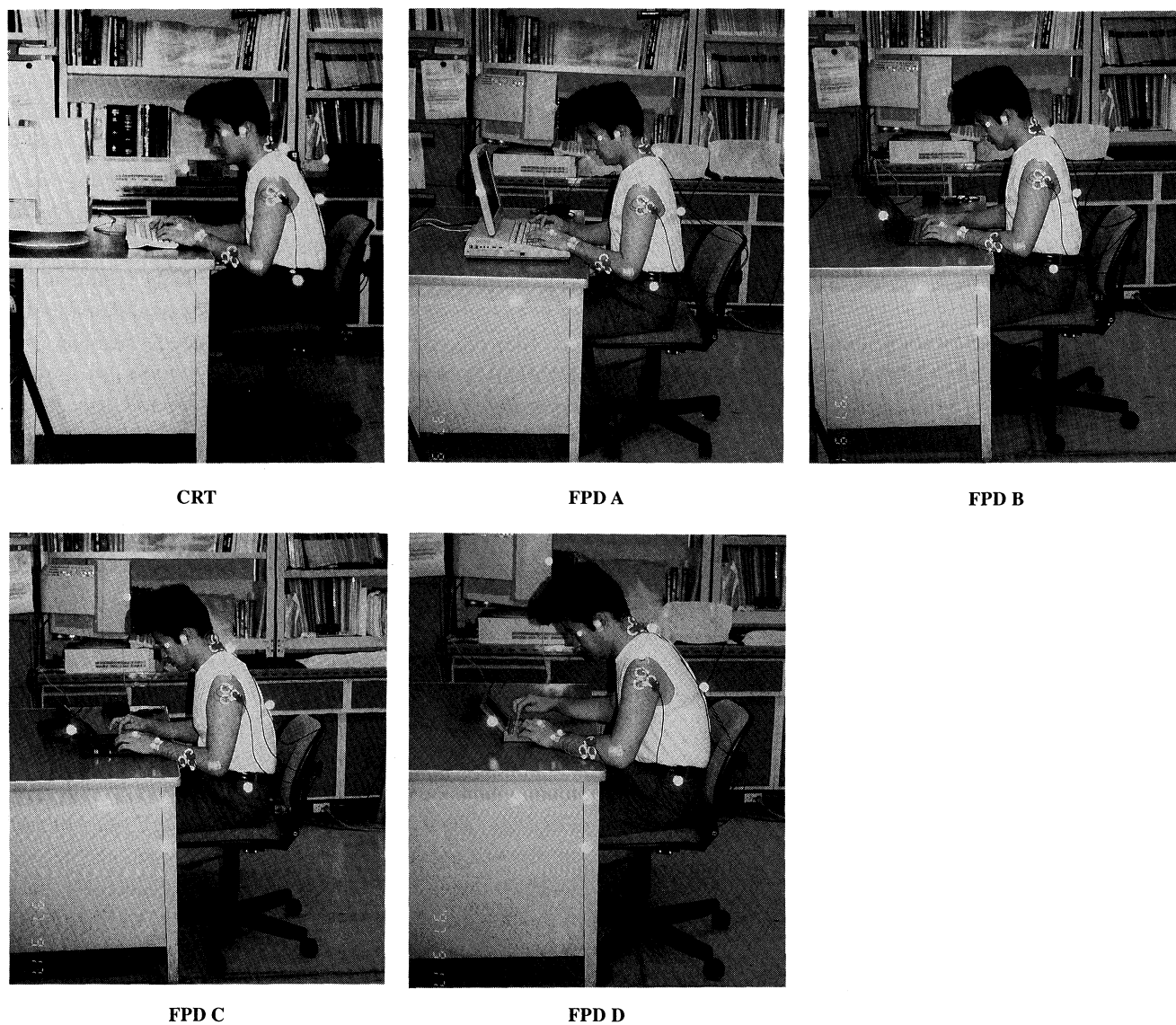


Fig. 3 The posture of one of the subjects while using the desktop computer(CRT) and FPD A, B, C and D

Table 4. Static and median EMG activities of the muscles evaluated during work with different display units‡

Display type	Neck extensor m.		Trapezius pars descendens m.		Deltoideus pars acromialis m.		Extensor carpi ulnaris m.	
	Static	Median	Static	Median	Static	Median	Static	Median
CRT	4.9 ± 3.6	7.5 ± 5.2	5.1 ± 5.0	8.5 ± 7.0	0.2 ± 0.3	0.6 ± 0.3	5.3 ± 3.1	9.6 ± 5.0
FPD A	5.8 ± 4.3*	8.1 ± 5.4*	5.8 ± 4.4	9.0 ± 5.9	1.3 ± 1.0*	1.9 ± 1.3*	7.2 ± 4.9	11.6 ± 7.4
FPD B	5.8 ± 4.3*	8.6 ± 5.5*	5.4 ± 5.2	9.5 ± 7.4	0.8 ± 0.6*	1.1 ± 0.7*	7.9 ± 4.7*	11.7 ± 6.4*
FPD C	6.7 ± 3.8*	9.1 ± 5.1*	5.7 ± 4.1	9.7 ± 6.0	0.4 ± 0.5	0.8 ± 0.5	5.7 ± 3.8	9.7 ± 5.9
FPD D	6.4 ± 3.0*	9.0 ± 4.3*	4.6 ± 4.5	7.8 ± 6.5	0.3 ± 0.4	0.6 ± 0.3	5.8 ± 4.3	9.9 ± 6.7

* significantly higher than in CRT ($p < 0.05$). ‡ integrated EMG activities expressed as percentage of the maximum voluntary contraction (%MVC).

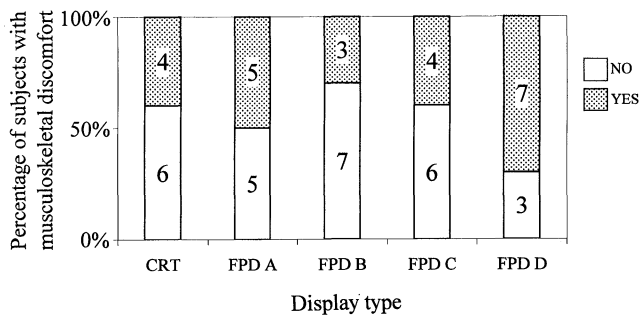


Fig. 4 Percentage of subjects with musculoskeletal complaints at each display unit

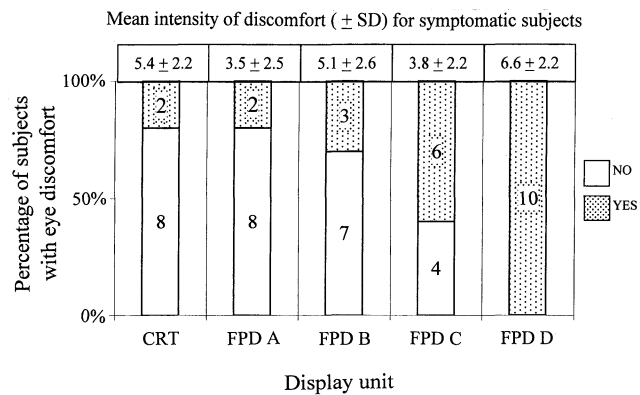


Fig. 5 Percentage of subjects with eye complaints at each display unit

activities, however, were recorded during work with the smallest display unit.

The results of the discomfort survey are shown in Figs. 4 and 5. Musculoskeletal complaints were noted with the use of all 5 display units but were highest for FPD D. When the location of the discomfort was looked into, the complaints were confined to the neck, shoulder, elbow and wrist areas. The most number of subjects with complaints per body region was also noted during use of the smallest display unit. For subjects with complaints, the highest intensity was again seen in FPD D.

The eye discomfort trends were similar with the musculoskeletal complaints. The largest proportion of subjects experienced eye discomfort during operation of FPD D. The average discomfort intensity was also highest for FPD D.

The subjects ranked the display units according to their preference (Fig. 6). The ratings showed that the subjects preferred to work with larger-sized displays and keyboards. The CRT was adjudged to be the easiest to work with in

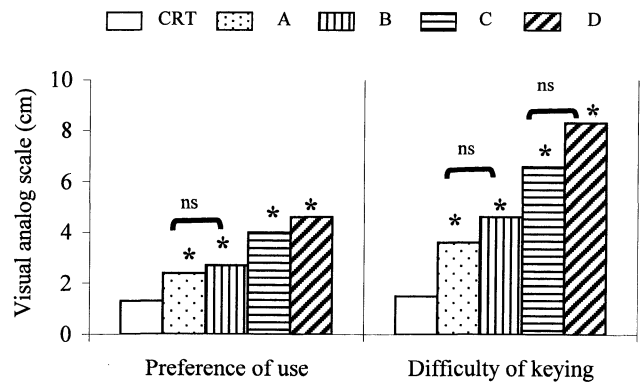


Fig. 6 Rating of display types for preference of use and difficulty of keying

*: significantly different from CRT ($p < 0.05$). ns: no significant difference between adjacent displays.

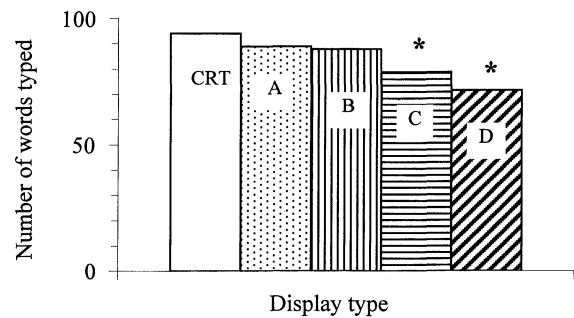


Fig. 7 Performance of the subjects at each display unit

*: significantly different from CRT ($p < 0.05$).

terms of keying. This view was validated by the subjects' first preference for use. Likewise, the rating for the difficulty of keying was also validated by the performance of the subjects. Performance was significantly lower for FPDs C and D. The lowest number of words typed was observed for the smallest FPD (FPD D) as shown in Fig. 7. Though not significantly different from the CRT, the performance with FPDs A and B exhibited a decreasing trend.

Discussion

To achieve mobility without compromising the basic functions, notebook portable computers were constructed as compact devices. However, the resulting features may be adjudged to be undesirable based on the existing ergonomic principles espousing adjustability and customizability of workstations⁸. Though limited in number, existing studies on portable computers have already shown

the disadvantages to its users. Measures of visual comfort were found to be inferior when portable computers are used in comparison to computers with CRT displays⁹. Visual ergonomic problems may stem from the difficulty of attaining the optimum luminance contrast and uniformity of the screen, reflection glare from the screen surface, and lowered viewing angle, among others. Constrained postures with the use of PC-FPDs have also been noted in earlier studies^{2, 10, 11}. Analysis of body motion and positions during work with portable computers has already pointed to the lower monitor height as the primary cause of constrained postures^{2, 10}. The minimal adjustment that can be made to accommodate individual differences in anthropometric characteristics is another factor leading to adverse posture. These earlier studies, however, only evaluated the ergonomic aspects of working with the A4-size PC-FPD. The need to evaluate other sizes of VDUs that are in the market still exists particularly in some conditions where the trend is to replace desktop computers with the PC-FPDs.

The results of the present study show the interaction between the workstation and the eye position and posture assumed by the subjects. The subjects preferred a more backward tilted screen for smaller VDUs to attain a better view of the visual target. The VDU settings noted may also be intended to attain the optimum luminance contrast, to eliminate the reflection glare on the screen and to complement the postural adjustments observed among the subjects.

The susceptibility of the neck and trunk position to changes in screen height is again highlighted in this experiment^{7, 12, 13}. With the decrease in size and ensuing height of the screen, there was a corresponding lowering of the neck and viewing angles. The trunk was noted to be relatively more inclined forward when using the smaller-sized screens. However, the adverse effects on posture were not limited to the torso but also on the upper extremities. The greatest wrist extension was observed during use of FPD B. The thin keyboard design of FPD B, which also produced the least keyboard inclination, may have induced this posture of the wrist. In all postural parameters analyzed that were significantly different from those noted with CRT use, FPD D (the smallest VDU) fared the poorest.

The evaluation of the muscle activities showed similar trends already noted with the postural analysis. The neck muscle activities were increasing with the decrease in display size as a function of display height and neck flexion. Again, the highest activation of these muscles was seen with the smallest VDU. The readability of the text presented at each display unit may also contribute to the assumed posture and

consequently, levels of the muscle activities. With the decreasing clarity of the image with smaller VDUs, the subjects may prefer to move closer to the visual target by increasing the degree of neck flexion.

The present study did not note any difference in trapezius muscle activities for the displays evaluated presumably because of the possibility for more forearm support despite the increasing forward trunk inclination with smaller FPDs¹⁴. Other factors that may account for this finding may be a relatively more inward shoulder rotation noted during FPD use and the seemingly constant extent of shoulder flexion. Only during operation of FPD B were the EMG activities of the extensor carpi ulnaris muscle significantly greater than with CRT use. The significantly greater extension of the hand at the wrist joint using the said PC-FPD may have activated the extensor carpi ulnaris muscle more than the other VDUs. EMG activities of the deltoideus muscle activities were highest during operation of FPD A and FPD B despite the statistically insignificant differences in the degree of shoulder abduction across all displays evaluated. The PC-FPDs mentioned have relatively extreme keyboard thickness and inclination angles. FPD A has the most inclined and thickest keyboard among the VDUs used in the study. Measurement of the dimensions of FPD B showed that it had the least inclined and thinnest keyboard. These extreme measures may have produced higher isometric tension in the deltoideus muscle, irrespective of the upper limb posture.

Musculoskeletal complaints can be associated with constrained postures. With smaller FPDs, greater neck flexion and forward trunk inclination have been observed. The intensities of neck and shoulder complaints were also increasing as the display used became smaller. The intensities of the discomfort in the elbow and wrist areas were greatest for symptomatic subjects while using FPDs B and D. The factor of VDU size may account for these results but this may be true only for FPD D. With regards FPD B, the role of the keyboard inclination and thickness cannot be discounted. The resulting relatively greater wrist extension from the use of the latter display may explain the intensity of the pain in the same area. Moreover, it cannot be completely ruled out that the wrist position observed with FPD B use may have also brought about contact stress to the elbow.

The percentage of subjects complaining of eye discomfort became higher with smaller VDUs. This may be related with decreasing readability of characters with decreasing VDU size. The intensities of the eye complaints at each VDU were also evaluated. Though not statistically

significant, the mean intensity was greatest during use of the smallest VDU (FPD D).

The smallest FPD was least preferred of all the VDUs used. Performance was also lowest for this display type. Reasons for the subjective and objective findings of display inferiority may be due to the relative difficulty of keying and higher discomfort complaints while using the smaller VDUs. Straker *et al.*¹¹⁾ presented performance results to the contrary. However, their results only apply to FPDs with sizes similar to FPD B used in this experiment. The lower performance and preference indices in this experiment were noted for FPD sizes less than FPD B.

Conclusion

This study shows that PC-FPDs have ergonomic attributes different from the desktop computers. The subjective and objective results of the experiment revealed that posture, muscle loading, acute health response and performance may be adversely affected by the PC-FPDs. Caution must, therefore, be exercised when slimmer and more compact PC-FPDs are introduced to the workplace. Hardware designers may consider the possibility of incorporating additional features to allow greater opportunities to adjust and vary the PC-FPDs' settings, such as keyboard inclination, monitor tilt, monitor height, viewing distance, etc. The lighting conditions in the workplace should not be neglected in view of the inherent limitations in the image quality produced by the PC-FPDs. The advantages must be weighed against the disadvantages before considering the use of PC-FPDs as alternative to desktop computers in order to safeguard the health and safety of its users. An ergonomic guideline specific for PC-FPD users is, likewise, needed to prevent the surge in health disorders previously seen among desktop computer users.

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