Ergonomic Evaluation of Working Posture of VDT Operation Using Personal Computer with Flat Panel Display

Shin SAIITO1*, Masaru MIYAO2, Takaaki KONDO3, Hisataka SAKAKIBARA3 and Hideaki TOYOSHIMA3

1 Department of Human Sciences, Aichi Mizuho College, Haiwa, 86-1, Hiratobashi-cho, Toyota 470-03, Japan
2 Graduate School of Polymathematics, Nagoya University, Chikusa-ku, Furou-cho, Nagoya 464-01, Japan
3 Department of Public Health, Nagoya University School of Medicine, Tsurumai-cho, 65, Showa-ku, Nagoya 466, Japan

Received January 9, 1997 and accepted February 4, 1997

Abstract: The aim of this study was to evaluate working conditions using a personal computer with a flat panel display (FPD) in terms of visual and musculoskeletal comfort. Measurements of viewing distance, viewing angle, head angle, neck angle and electromyogram (EMG) activities of the neck, shoulder and back muscles of visual display terminal (VDT) operators were compared at workstations using an FPD and a desktop personal computer (DPC). A notebook personal computer (NPC) with a 10.4 inches FPD, was used in this experiment. Each of 10 healthy subjects performed word processing tasks using both NPC and DPC workstations. Significant differences in the work posture while using the NPC and DPC were seen with viewing distance, viewing angle and head angle. The characteristic features of the work posture using the NPC were a remarkably short viewing distance and a forward inclination of the head. The value of integrated EMG (IEMG) of the neck muscle was greater while using the NPC than when using the DPC. These phenomena were caused by the structure of NPCs; most NPCs have a display and keyboard which cannot be separated and are not adjustable without tilt and swivel mechanisms. VDT devices that cannot be adjusted may potentially make operators assume a poor posture while working, which could cause visual and musculoskeletal disorders. To prevent visual and musculoskeletal problems using NPCs, a more upright head and neck position was recommended. The addition of a mechanism for adjustment of the height of an NPC display would allow a comfortable downward gaze without the loss of correct posture.

Key words: Visual display terminal (VDT), Workstation, Notebook personal computer, Flat panel display (FPD), Work posture, Musculoskeletal, Electromyogram (EMG)

Introduction

As a result of the progress in flat panel display (FPD) production technology in recent years, FPDs have come into wide use in many workplaces, and this trend is expected to increase in the near future, because FPDs have the advantages of being portable, space saving, and energy saving in comparison with desktop personal computers (DPCs) with cathode ray tubes (CRTs). Mobile type personal computers with FPDs, which are called notebook personal computers (NPCs), are becoming increasingly popular on the market. There have been many reports on guidelines and
recommendations for visual display terminal (VDT) operation using DPCs\(^1\), but very few ergonomic evaluations of the workload at workstations using NPCs. A few reports have examined the visual characteristics of FPD\(^3\) such as readability, response of lens accommodation and pupillary reflexes\(^4\-6\). The viewing conditions of FPD were inferior to that of CRTs. Another disadvantage of an NPC is that the display and keyboard cannot be separated and are not adjustable without tilt and swivel mechanisms. VDT devices that cannot be adjusted may cause operators to assume a poor posture while working, which could cause musculoskeletal disorders\(^7\). Besides, there are no guidelines concerning VDT operation using NPCs.

The purpose of this study was to evaluate working conditions using NPCs in terms of visual and musculoskeletal comfort. An NPC with a 10.4 inches FPD, was used in this experiment. Ergonomic problems were identified and examined when an operator performed VDT operation using the NPC. The following factors were analyzed and compared when the NPC and DPC were used; viewing distance and angle, head and neck posture, and electromyogram (EMG) activities of the neck, shoulder and back muscles.

**Materials and Methods**

**Materials**

Two kinds of workstation devices were given to each subject, an NPC and a DPC. An NPC with a liquid crystal display (LCD), model PC-9801NC (NEC Corp., Tokyo) was used. The LCD was a 10.4 inches color display. The DPC was a model PC-9801BX2 (NEC Corp., Tokyo) with a 14 inches color CRT display CMT-B14U2S (SANYO Electric Corp., Osaka). The CRT display was put on a central processing unit (CPU) box on the top of the desk. The most prevalent business desk height of 700.0 mm was selected for the desk in each workstation. The distance from the keyboard to the desk edge was 40.0 mm for each workstation. The height of the chair at each workstation was adjustable and had a backrest.

**Subjects**

Ten healthy students, 5 females and 5 males, whose ages ranged from 18 to 22 years (average age: 19.8 years) were selected as subjects. They all frequently used VDTs with word processing and spreadsheet programs, but were not touch-typists.

**Procedure**

Each subject was asked to sit on a chair whose height was adjusted appropriately. The subjects engaged in the VDT tasks; typing a document on a word processor in Japanese for 30 min. The experiment was carried out at individual workstations using the NPC and DPC. The position of the workstation devices were fixed during the task. The subjects were allowed to use the chair’s backrest.

In order to get accustomed to the operation, the subjects performed the VDT tasks at each workstation for 30 min before the measurements started. The data from the last 10 min was analyzed for each subject.

**Posture analysis**

To evaluate the work posture, video tape recorder (VTR) images of the subjects performing VDT tasks were recorded by a VTR camera, model CCD-TR3 (SONY Corp., Tokyo), from the right profile. The data were consequently analyzed by frame analysis for 10 min, at a sampling rate of every 2 sec. One distance and three angles were defined and measured from the VTR frames as the analysis parameters shown in Figure 1. The parameters of viewing distance, viewing angle, head angle and neck angle were defined as follows;

**Viewing distance (L):** The distance between the eye and the center of the display.

**Viewing angle (ΘV):** The angle formed by the line of the viewing distance and the horizontal plane.

**Head angle (ΘH):** The angle formed by the Reid’s line and the horizontal plane. Reid’s line was defined by a line connecting the outer canthus of the eye and the center of the outer canal of the ipsilateral ear.

**Neck angle (ΘN):** The angle formed by the line between the acromion and the center of the outer canal of the ipsilateral ear and the horizontal plane.

The value of the angle formed by an upward movement in a clockwise direction was defined as positive, and a downward movement was defined as negative.

**EMG analysis**

To evaluate the activities of the neck, shoulder and back muscles, four kinds of muscles were selected and recorded as EMG. Figure 2 shows the locations of electrodes for these muscles;
Deltoid muscle: The right side of the deltoid muscle.
Neck muscle: The erector spinae cervicalis covered by the right side of upper part of the trapezius muscle.
Shoulder muscle: The right side of the trapezius muscle pars transversa covering supraspinatus.
Upper back muscle: The erector spinae thoracalis covered by the right side of trapezius muscle.

Flexible disposable surface electrodes were attached to the skin in the direction of these muscles. The signal of EMG was amplified by a multi-channel bioamplifier, model Polygraph 363 (NEC Medical Systems Ltd., Tokyo), and recorded on a digital tape recorder, model RD145-T (TEAC Corp., Tokyo). The EMG activity was integrated for 10 min to produce an integrated EMG (IEMG).

Statistical analysis
Paired t-test was used to evaluate the results of the difference of the work posture of the NPC with the DPC. A correlation coefficient was calculated for the posture parameters. Wilcoxon's signed rank sum test was used to compare the difference of the IEMG of the NPC with the DPC. Statistical tests with p<0.05 were considered to be significant.

Results

Work posture
Table 1 shows the results of the posture analysis. The average viewing distance for the NPC was 329.1 mm, 18.9% shorter than the value for the DPC (405.7 mm). Paired t-test analysis revealed a significant difference between the average viewing distance with the NPC and with the DPC (p<0.01).

The average viewing angle (θV) with NPC use was -35.0 deg and that with the DPC was 0.3 deg, indicating a more downward direction with the NPC. This implies that the vertical eye position was affected by the height of the display, since the DPC display height was 205.0 mm higher than that of the NPC. Paired t-test analysis revealed a significant difference between the average values for viewing angles with the NPC and with the DPC (p<0.01).

The average head angle (θH) with NPC use was -22.0 deg, 16.4 deg lower than with DPC use (-5.6 deg; Table 1) indicating a more forward head inclination with NPC use. Paired t-test analysis revealed a significant difference between the average values for head angles with the NPC and with the DPC (p<0.01). An example of the traced changes in the head angle for one subject is presented in Figure 3.

Table 1. Average and SD of viewing distance, viewing angle, head angle and neck angle while using NPC and DPC

<table>
<thead>
<tr>
<th></th>
<th>NPC</th>
<th>SD</th>
<th>DPC</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viewing distance (L: mm)</td>
<td>329.1</td>
<td>54.4</td>
<td>405.7</td>
<td>43.0**</td>
</tr>
<tr>
<td>Viewing angle (θV: deg)</td>
<td>-35.0</td>
<td>5.6</td>
<td>0.3</td>
<td>7.5**</td>
</tr>
<tr>
<td>Head angle (θH: deg)</td>
<td>-22.0</td>
<td>10.0</td>
<td>-5.6</td>
<td>15.7**</td>
</tr>
<tr>
<td>Neck angle (θN: deg)</td>
<td>48.2</td>
<td>13.7</td>
<td>52.0</td>
<td>12.3 NS</td>
</tr>
</tbody>
</table>

NS: not significant. **: p<0.01 (n=10).
The changes in the head angle with NPC use were smaller than those with DPC use. Table 2 shows the average value of the head angle and its standard deviation for each subject. Less change of the head angle were also observed in all subjects.

The average value of the neck angle ($\theta_N$) with NPC use was 48.2 deg and with DPC use was 52.0 deg. The neck angle was therefore not significantly affected by a change in workstations.

Significant differences in work posture between NPC and DPC use were therefore observed with viewing distance, viewing angle and head angle. Work posture using the NPC was characterized by a remarkably short viewing distance and forward head inclination.

Table 3 shows the correlation coefficients ($r$) between viewing distance and head angle, and viewing distance and neck angle, using the NPC and DPC. A correlation coefficient was calculated for each subject. Both NPC and DPC use showed a positive correlation between viewing distance and head angle, between viewing distance and neck angle. This means the more upright the head and neck were, the longer the viewing distance became.

**EMG activities of the neck, shoulder and back muscles**

Table 4 shows the results of the average, maximum and minimum values of IEMG for 10 min of four muscles found in 10 subjects. Wilcoxon's signed rank sum test analysis revealed a significant difference between IEMG of the neck muscle while using the NPC and DPC ($p<0.05$).

---

**Table 2. Average and SD of head angle for each subject (deg)**

<table>
<thead>
<tr>
<th>Subject No.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>NPC Average</td>
<td>-29.8</td>
<td>-17.2</td>
<td>-19.5</td>
<td>-18.7</td>
<td>-22.8</td>
<td>-32.9</td>
<td>-24.7</td>
<td>-35.0</td>
<td>-19.6</td>
<td>0.5</td>
</tr>
<tr>
<td>SD</td>
<td>8.0</td>
<td>4.2</td>
<td>6.5</td>
<td>3.1</td>
<td>4.9</td>
<td>4.4</td>
<td>3.8</td>
<td>8.7</td>
<td>5.6</td>
<td>4.0</td>
</tr>
<tr>
<td>DPC Average</td>
<td>29.9</td>
<td>-2.7</td>
<td>-14.5</td>
<td>-8.9</td>
<td>-8.5</td>
<td>4.7</td>
<td>-19.6</td>
<td>-26.4</td>
<td>-12.9</td>
<td>2.9</td>
</tr>
<tr>
<td>SD</td>
<td>15.2</td>
<td>10.4</td>
<td>9.6</td>
<td>6.9</td>
<td>7.7</td>
<td>7.0</td>
<td>8.4</td>
<td>19.0</td>
<td>8.2</td>
<td>5.1</td>
</tr>
</tbody>
</table>

**Table 3. Relationship between viewing distance and head angle, neck angle in each workstation**

<table>
<thead>
<tr>
<th></th>
<th>Head angle</th>
<th>Neck angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>NPC</td>
<td>+0.37</td>
<td>+0.62</td>
</tr>
<tr>
<td></td>
<td>(+0.04 - +0.79)</td>
<td>(+0.37 - +0.82)</td>
</tr>
<tr>
<td>Viewing distance</td>
<td>+0.53</td>
<td>+0.68</td>
</tr>
<tr>
<td></td>
<td>(+0.19 - +0.80)</td>
<td>(+0.37 - +0.83)</td>
</tr>
</tbody>
</table>

Median of correlation coefficients for 10 subjects. Range of correlation coefficients in parenthesis.

**Table 4. Comparison of IEMG activities between NPC and DPC (Arbitrary Unit)**

<table>
<thead>
<tr>
<th>Muscles</th>
<th>NPC</th>
<th>DPC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deltoid</td>
<td>Average</td>
<td>19.0</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>49.2</td>
</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>4.6</td>
</tr>
<tr>
<td>Shoulder</td>
<td>Average</td>
<td>51.8</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>81.9</td>
</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>12.5</td>
</tr>
<tr>
<td>Neck</td>
<td>Average</td>
<td>23.8</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>42.5</td>
</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>12.2</td>
</tr>
<tr>
<td>Upper back</td>
<td>Average</td>
<td>25.1</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>36.7</td>
</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>8.2</td>
</tr>
</tbody>
</table>

NS: not significant, *: $p<0.05$ (n=10).
Discussion

The average viewing distance was markedly shorter with NPC than with DPC use, and the subjects’ head inclined further forward when using the NPC. A short viewing distance increases visual disorders such as symptoms of visual fatigue, transient myopia and changes of accommodative response\(^8\)\(^-\)\(^10\). Some ergonomic guidelines for VDT workstations recommend a viewing distance in the range of 300–700 mm\(^1\)\(^-\)\(^2\). It was reported that the preferred viewing distance was on average 650 mm, and in the range of 500–810 mm\(^11\). The NPC average viewing distance of 329.1 mm in this experiment was shorter than that of the resting point of the accommodation and vergence system\(^10\)\(^,\)\(^12\). Consequently, it is necessary for operators using NPCs to maintain an appropriate viewing distance.

Workstations with the NPC caused downward gaze compared with the DPC. The physiological disadvantages of an upward gaze have been identified in recent studies as follows; an increase in ocular surface area\(^13\), a further shift in dark vergence\(^14\) and an increase in the angle of exophoria\(^15\). The average value of the vertical eye position with DPC use was found to be higher than that of NPC use previously\(^16\). Therefore, NPC use should remove the physiological problems caused by an upward gaze, since the height of the display is lower than that of the DPC.

Less changes of the head angle were observed with NPC use. It was reported that a human can obtain visual information with only eye movement is 30.0 deg in the horizontal direction (left direction: 15.0 deg, right direction: 15.0 deg) and 20.0 deg in the vertical direction (upward direction: 8.0 deg, downward direction: 12.0 deg)\(^17\). At a visual distance of 400.0 mm, the estimated range that can be obtained visual information with only eye movement is 214.2 mm in the horizontal direction and 141.4 mm in the vertical direction. This range is large enough to cover the NPC used in this experiment, and the subjects may look at both the display and keyboard with eye movement only without head movement. Moreover, it is also estimated that less changes of head angle may be caused by the visual characteristics of the FPD. That is to say, the subjects may be restricted to a certain position to obtain a clear view of the display, because most FPDs, especially LCDs, show changes in luminance contrast with different view angles.

It was reported that the neck angle was significantly affected by changes in the display height\(^18\). However, the neck angle was not significantly affected by a change at the both workstations in this experiment. The differences of these results might depend on the definitions of the measuring parameters. The neck angle of that report was equal to the head angle in this experiment. Therefore it is obvious that the head position was affected by the display height.

When using the NPC, the IEMG value for the neck muscle was significantly greater than that with the DPC. It was considered that this phenomenon was caused by the forward inclination of the head\(^19\). In addition, less head movement makes operators sustain static muscle work\(^20\)\(^,\)\(^21\), which causes an increase in intramuscular tissue pressure which could produce ischemia of the trapezius muscle\(^22\)\(^,\)\(^23\). The forward inclination of the head and neck may increase the mechanical load of the moment at the seventh cervical vertebra\(^24\), and the loads of the neck and shoulder muscles, which may produce musculoskeletal disorders\(^25\)\(^,\)\(^26\). Analysis of correlation coefficients suggested that the increase of viewing distance and the decrease of forward inclination may make the head and neck a more upright position.

As a result, the visual and musculoskeletal workloads caused by the poor posture with NPC use is considered to be greater than with DPC use, except for the physiological advantage of the downward gaze. This problem arises because the display and keyboard of the NPC cannot be separated, causing the operator to assume a poor posture, such as a short viewing distance and a forward inclination. A more upright position of the head and neck was recommended for VDT operators based on analysis of the correlation coefficients. A more upright posture should reduce the EMG activity of the neck muscle. This recommendation is supported by Villanueva et al. that the viewing distance became longer when the trunk position maintained a backward-leaning\(^18\).

A previous study on DPCs by Grandjean recommended that the display and keyboard be separate and adjustable\(^23\). The results of this study of NPC use also indicate that the keyboard and display need to be able to be separated to allow adjustment of the height of the display in order to avoid a short viewing distance and an excessive forward inclination of the head, while maintaining a comfortable downward gaze.

Conclusion

To prevent visual and musculoskeletal disorders using NPCs, these VDT devices should be arranged to give each operator a more upright head and neck position. This posture is better able to maintain an appropriate viewing distance, and to decrease the loads on the neck and shoulder muscles. Most NPCs have a display and keyboard which cannot be
separated and are not adjustable. The addition of a mechanism for adjustment of the height of the NPC display would allow a comfortable downward gaze without the loss of correct posture.

Acknowledgments

The authors are deeply grateful to Dr. Susumu Saito, Dr. Midori Sotoyama, National Institute of Industrial Health, Japan, Dr. Sasitorn Taptagaporn, Ministry of Public Health, Thailand, Mr. Toru Suzuki, University of Occupational and Environmental Health, Japan and Dr. Zoujiro Katoh, Aichi Mizuho College, Japan for their valuable advice and help.

This study was partly funded by a grant-in-aid for scientific research from the Japan Ministry of Education, Science, Sports and Culture (Grant number: 06770268).

References

22) Sadamoto T, Bonde-Petersen F, Suzuki Y (1983) Skeletal muscle tension, flow, pressure, and EMG during


