Industrial Health 1997, **35**, 330–336

Sitting Posture and Neck and Shoulder Muscle Activities at Different Screen Height Settings of the Visual Display Terminal

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Received April 2, 1997 and accepted May 15, 1997

Abstract: The effects of the VDT screen height on working posture and electromyographic (EMG) activities of the neck and shoulder muscles were determined in 10 healthy subjects. The subjects performed a mouse-driven interactive task at the screen height settings of 80, 100 and 120 cm. Changes in body positions were measured by video image and frame analysis. Surface EMG recordings were done on the neck extensor muscle and the descending part of the trapezius muscle, both on the right side. The results of the postural analysis showed that at higher screen height settings, the neck became significantly more erect. The subjects also assumed a more backward-leaning trunk position at higher screen heights. The EMG activities of the neck and shoulder muscles were related to the neck angle and trunk inclination, respectively. A more flexed neck produced significantly higher neck extensor muscle activities. A backward-leaning trunk was also noted to decrease trapezius muscle activity in some subjects.

Key words: Visual display terminal (VDT), Screen height, Posture, Neck extensor muscle, Trapezius muscle, Electromyography (EMG)

Introduction

Working with the visual display terminal (VDT) is primarily a visual task. The body movements support the eye position in attaining the optimum viewing angle while performing the VDT work[1, 2)]. Mutually interrelated movements of the body are involved in adapting to the workstation with priority given to the eye[3, 4)].

The position of the head is the extremely important in setting the preferred viewing angle[3, 5)]. This is more pronounced in VDT work that needs constant visual monitoring of the screen. For interactive work, such as computer-aided design (CAD), which requires attention to the screen in more than 50% of the working time[6)], postural fixation ensues once the viewing angle has been set[4)]. With the introduction of the mouse as a primary input device for graphical user interfaces, body movements may be concentrated on the hand handling of the mouse, precluding further change in posture. Unvaried, simplified body motions and constrained and awkward postures are produced leading to the static loading of the same muscle groups that can cause pains and fatigue[7, 8)].

For VDT workers performing keyboard tasks, constrained postures of the neck and shoulder are frequently implicated as significant risk factors in the development of musculoskeletal complaints[9–11)]. Forward flexion of the neck creates an increased moment of the head weight that can produce significant contraction of the muscles to achieve

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equilibrium[12,13]. The problem of neck discomfort has been shown to occur concurrently with shoulder discomfort in several studies[14,15]. These symptoms were found to be similarly experienced by mouse users[16].

Some authors have studied how posture can be improved by changing the workstation. Increasing the VDT monitor height resulted in a head that is less bent and a trunk that is more erect[4,17]. This erect posture may produce less muscle tension and lesser load on the spine compared to a flexed upper body[2,18].

In the present study, manipulation of the workstation was done to determine the changes in the body positions and the electromyographic (EMG) activities of the neck extensor muscle and the descending part of the trapezius muscle. The VDT screen height was modified while performing a non-keyboard task. The relationship between posture and muscle activity at the different screen setting was explored.

Subjects and Method

Subjects

Ten subjects (8 male and 2 female) participated in the experiment. All subjects are right-handed. The demographic characteristics are shown in Table 1.

Table 1. Descriptive statistics on demography and anthropometry of the subjects

Subjects	n=10	
Gender	female: 2 male: 8	

	MEAN ± SD	RANGE
Age	29.3 ± 10.6 years	21–51
Height	170.1 ± 5.0 cm	159–177
Seated height	127.2 ± 2.9 cm	123–131
Eye height	122.1 ± 2.9 cm	117–126
Chair height	43.0 ± 1.8 cm	41–45.5

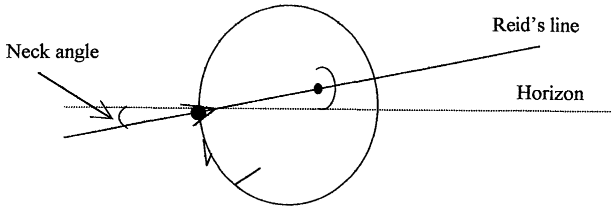

Fig. 1. Measurement of neck angle based on the Reid's line

Experimental workstation

The selection of the 3 screen height settings, i.e., 80, 100, and 120 cm, used in the experiment was based on the recommended table height of 67 cm[19]. The central processing unit (CPU) and the 14-inch CRT monitor placed on top of a 67 cm table resulted in a screen height of 100 cm (from the floor to the middle of the screen). Change of screen height was made at 20-cm increments.

The table height upon which the mouse rests was constant for all subjects at 67 cm. The mouse table is detached from the adjustable screen table.

Prior to the start of the experiment, the subjects were asked to adjust the chair until the forearm was parallel to the ground when handling the mouse. The back support was adjusted to desired levels. Thereafter, the chair setting remained unchanged throughout the experiment.

Task

The subjects were asked to engage in an interactive computer game requiring constant visual monitoring. Only the mouse was used as the input device in this experiment. The subjects performed the VDT task for 20 min at each screen height. The subjects were allowed to adapt to the workstation for 5 min. Data for the next 15 min was used for analysis in this study. Posture and muscle activities were recorded intermittently every minute for the duration of the experiment. Rest of 1 hr was introduced in between height changes. The order of the change in screen height was completely randomized.

Posture analysis

Body positions at different screen height settings were captured by a video camera from the left profile of the subject. Posture was analyzed using a video image analyzer and by frame analysis of the videotape recording[4,20]. Posture was recorded intermittently every minute for the duration of the experiment. Five frames were taken per minute.

The neck angle was based on the Reid's line referenced to the horizontal plane. The Reid's line is defined by a line connecting the outer canthus of the eye and the center of the outer canal of the ipsilateral ear (Fig. 1). Earlier findings showed that the Reid's line is approximately 10° above the Frankfurt plane.

Thoracic bending was defined as the angle formed by 7th cervical vertebra (C7), angulus inferior scapula and iliac crest. A smaller angle corresponds to a relatively more kyphotic spine.

Trunk inclination was determined using the angle formed

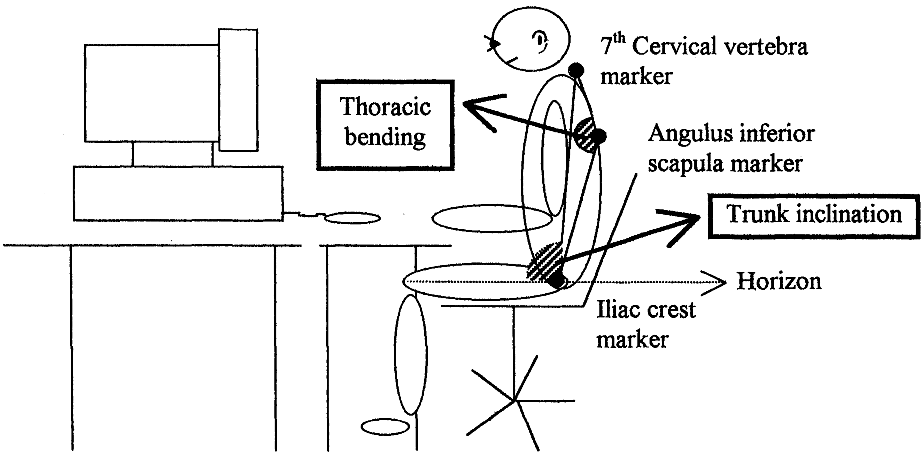

Fig. 2. Location of markers and measurement points for the postural angles

by C7 and iliac crest referenced against the horizontal plane. Reclining positions would assume a value of more than 90° (Fig. 2).

Electromyography

Disposable 8 mm AgCl surface electrodes (Blue Sensor, Medicotest A/S, Denmark) were attached on the skin of the subjects. Prior to attachment, the skin was cleaned with 70% ethanol. The location of the recording electrodes were as follows: 1) at the level of the 2nd or 3rd cervical vertebra (C2–C3), right paravertebral, over the cervical portion of the descending part of the trapezius muscle to record the activity of the neck extensor muscles; and 2) at the midpoint between the right acromion and the spine of the right 7th cervical vertebra (C7), to record the activity of the trapezius pars descendens muscle. Ground electrodes were attached lateral to the recording electrodes.

A portable EMG machine (MEGA ME3000P, Mega Electronics, Ltd., Kuopio, Finland) was used to record the muscle activities. Recording was done intermittently every minute. Sampling of the muscle activity was done at a frequency of 1000 Hz. The recorded activity was downloaded to an EMG analyzer (MEGA ME3000P, Mega Electronics, Ltd., Kuopio, Finland) where full rectification and time averaging every 100 msec for 5 sec was done. The procedure was performed for all subjects doing the VDT task at 3 different screen height settings.

To facilitate interindividual comparison, the muscle activity was normalized as percentage of the maximum voluntary contraction (MVC) after data gathering for the 3 height settings was completed. Manual resistance was placed over the occiput during attempted neck extension to get the MVC of the neck extensor muscles covered by the cervical portion of the m. trapezius, pars descendens. Manual resistance was placed over the shoulder during attempted shoulder elevation to get the MVC of the anterolateral portion of the m. trapezius, pars descendens.

Statistical analysis

Non-parametric statistical analysis methods were employed because the data gathered were not normally distributed. Friedman's oneway repeated measures analysis of variance on ranks was used to determine the effect of screen height on posture and muscle activity. Results of repeated measures ANOVA were subjected to Student-Newman-Keul's method of multiple comparison to determine significant difference between levels of the test variable. Correlation studies were performed using Spearman's rank order and Pearson's correlation analysis methods. Statistical tests with $p<0.05$ were considered significant.

Results

Body posture and screen height

The neck angle and trunk inclination were significantly affected by changes in screen height (Table 2). The neck became more erect at higher screen positions ($p<0.001$). The trunk was also noted to be more backward-leaning as the screen height was increased ($p=0.02$). Student-Newman-Keul's multiple comparison studies showed that the neck was becoming significantly more upright from the lowest to the highest screen height ($p<0.05$). For trunk inclination, however, the difference was not significant between the means at 80 and 100 cm.

Table 2. Mean values of postural angles and muscle activities at different height settings

Screen height (cm)	Neck angle (deg)	Thoracic bending (deg)	Trunk inclination (deg)	Neck extensor muscle activity (% of MVC)	Trapezius pars descendens muscle activity (% of MVC)
80	− 2.0 ± 5.6 (− 21 to 8)	118.2 ± 5.4 (106.7–124.5)	93.3 ± 8.4 (79.3–107.3)	10.4 ± 3.7 (3.8–18.6)	3.1 ± 1.7 (0.2–9.6)
100	8.9 ± 6.3 (− 5.8 to 20.3)	118.8 ± 4.4 (109.0–124.9)	97.2 ± 6.8 (85.3–115.1)	7.8 ± 2.4 (3.3–12.9)	2.6 ± 1.0 (0.6–9.7)
120	21.3 ± 5.8 (5.8–31.5)	120.4 ± 5.8 (110.0–128.5)	103.9 ± 10.8 (90.9–127.6)	5.4 ± 1.7 (1.6–5.7)	2.2 ± 1.0 (0.2–6.9)
Friedman repeated measures ANOVA on ranks	p<0.0001	*NS*	p=0.02	p<0.0001	*NS*
Student-Newman-Keul's multiple comparison	80 vs. 100* 100 vs. 120*	–	80 vs. 100^{ns} 100 vs. 120*	80 vs. 100* 100 vs. 120*	–

Values: mean standard ± deviation; (range). *p<0.05; *ns* not significant.

Table 3. Relationship of screen height and postural angles per subject

Subject	Height and neck angle	Height and thoracic bending	Height and trunk inclination
1	0.94***	0.88***	0.86***
2	0.94***	0.58***	0.75***
3	0.94***	0.56***	0.94***
4	0.94***	0.94***	0.94***
5	0.94***	0.35*	0.94***
6	0.94***	− 0.10	0.48***
7	0.94***	0.47***	0.94***
8	0.94***	0.74***	0.64***
9	0.94***	0.56***	− 0.32
10	0.94***	− 0.07	0.76***

Spearman's correlation: 2-tailed significance *p<0.05; **p<0.01; ***p<0.001.

Table 4. Mean frequency of neck flexion and trunk inclination at different height settings for 10 subjects

Screen height	Neck angle classification		Trunk inclination classification	
(cm)	<10°	≥10°	<90°	≥90°
80	15	0	6.8 ± 7.5	8.2 ± 7.5
100	7.1 ± 7.1	7.9 ± 7.1	1.5 ± 4.7	13.5 ± 4.7
120	0.4 ± 1.2	14.6 ± 1.3	0	15

The degree of thoracic bending showed no significant differences in the mean measurements at the different screen height settings. Nonetheless, a trend of the upper back becoming less bent may be noted with the increase in screen height.

The effect of screen height changes on posture was also analyzed intraindividually (Table 3). Spearman's correlation findings showed that all subjects displayed significant positive correlation between screen height and neck orientation referenced against the horizontal (mean coefficient of correlation=0.94). The same positive correlation existed between screen height and trunk inclination in all but 1 subject. In 8 out of 10 subjects, significant correlation was also seen between screen height and the angle that defines thoracic bending, i.e., the curvature of the upper body decreased when the height of the screen was increased.

The neck position was classified into 2 levels with reference to the horizontal. This angle corresponds to the Frankfurt plane parallel to the ground and a vertical neck position. Angles less than 10° would correspond to a bent neck posture. Neutral or extended neck positions would assume angles equal or more than 10°. The number of times the postural category was observed per subject was taken. The average for the 10 subjects was computed (Table 4). The results showed that at the screen height of 80 cm, the neck posture of all the subjects was in constant flexion. With the increase in screen height, the frequency of the neck assuming a flexed position decreased markedly.

The trunk position was also classified into 2 levels relative to the vertical plane (Table 4). A forward-leaning trunk would assume angles less than 90°. An erect or backward-leaning trunk inclination would have angle measurements of equal or greater than 90°. The average number of times the postural

Table 5. Mean frequency of observed postural classifications at different screen height settings for 10 subjects

Screen height (cm)	Postural Classification*			
	1 	2 	3 	4 
80	6.8 ± 7.5	9.7 ± 10.0	0	0
100	0	8.0 ± 6.7	1.5 ± 4.7	5.5 ± 6.4
120	0	0.4 ± 1.3	0	14.6 ± 1.3

*Posture 1: neck angle <10° and trunk inclination<90°, Posture 2: neck angle<10° and trunk inclination≧90°, Posture 3: neck angle≧10° and trunk inclination<90°, Posture 4: neck angle≧10° and trunk inclination≧90°.

Table 6. Relationship of postural angles and muscle activities per subject

Subject	Neck angle (deg) and neck extensor muscle activity (% of MVC)	Trunk inclination (deg) and trapezius pars descendens muscle activity (% of MVC)
1	− 0.93***	0.56***
2	− 0.80***	− 0.27
3	− 0.95***	− 0.34*
4	− 0.79***	− 0.60***
5	− 0.88***	0.02
6	− 0.89***	0.24
7	− 0.81***	− 0.50***
8	− 0.88***	0.58***
9	− 0.96***	− 0.18
10	− 0.86***	− 0.54***

Pearson's correlation: 2-tailed significance *p<0.05;** p<0.01; ***p<0.001.

category of trunk inclination was displayed was computed in the same way as for the categories of neck flexion. In this study, a backward-leaning trunk position was increasingly preferred as the screen height was raised. At the height of 120 cm, all subjects assumed a reclining position.

Macro-postural classification was done by combining the categories of neck and trunk position as defined earlier (Table 5). Again noted is the decreasing frequency of a flexed upper body at higher screen heights.

Muscle activities and screen height

The normalized EMG activities of the neck extensor muscle and the descending part of the trapezius muscle were compared across the screen height settings tested. The neck extensor muscle activities were significantly decreased as the height of the screen was increased (see Table 2). The highest mean EMG activities for the muscles tested were recorded at the screen height of 80 cm. The minimum and maximum levels (3.8% MVC and 18.6% MVC) of neck extensor muscle activity recorded at this screen height were also the highest compared to the other settings.

Shoulder muscle activities did not differ significantly across the different screen height settings but a trend of decreasing EMG activities with the elevation of the monitor placement was observed.

Relationship of body positions and muscle activities

Correlation analysis of muscle activities for each subject showed a consistently high coefficient of correlation for neck posture and neck extensor muscle activity. The coefficients of correlation ranged from $r = -0.79$ to $r = -0.96$. The decrease in neck flexion is invariably associated with the decrease in neck muscle activity (Table 6).

The level of trapezius muscle activity was also correlated with trunk inclination. Though 6 out of 10 subjects displayed significant coefficients of correlation, the direction of the relationship was noted to differ among the subjects. Results in 4 of the 6 subjects showed negative correlation between the degree of trunk inclination and trapezius muscle activity. With the increase in the degree of trunk inclination, a decrease in trapezius muscle activity was noted. The remaining 2 subjects showed positive correlation. With the increase in the degree of trunk inclination, the activation of the trapezius muscle increased.

Discussion

Screen height and posture

Musculoskeletal loads may be computed based on the moment of force created by postural angles of joints. Because of this biomechanical principle, posture becomes a useful indicator of work-related musculoskeletal disorders and a valuable tool in evaluating workstation design.

In this study, the height of the screen has been shown to affect significantly the posture of the subjects. As the height was raised, the neck became more vertical and the trunk assumed a more backward-leaning position. At the height of 80 cm, all subjects maintained the neck in a flexed position. When the screen height was adjusted to 100 cm, the subjects' heads were held vertical or in retroflexed position for about 50% of the experiment time. At the 120 cm-height, the subjects held their heads above the reference horizontal plane almost all of the time. Biomechanical concepts support that this significant trend of upright neck position will result in a considerable reduction of load on the neck.

According to Colombini *et al.*[2] and Andersson and Ortengreen[21], a reclining posture reduces the load on the vertebral disc and back muscles. Hence, lumbar muscle and disc load may be highest at the screen height of 80 cm when the forward-leaning trunk position was held by the subjects for almost 50% of the duration of this experiment. It can be predicted also that the load is significantly reduced at 100 cm when the frequency of forward-leaning trunk position was decreased by half and more so at 120 cm when all the subjects were backward-leaning for the entire duration of the experiment.

With a forward-leaning position and a relatively more kyphotic upper back, the shoulder muscles are adversely affected. Lowering and forward rotation of the shoulder may accompany a stooping posture[22]. Even slight degree of non-neutral shoulder position has been associated with increased shoulder muscle load[23]. The present study did not measure directly these shoulder positions. Nonetheless, if undesirable trunk and upper back positions have been associated with increased shoulder muscle load, then the improvement in posture as a result of increasing the screen height may decrease the load.

Screen height, EMG and posture

Electromyography was performed to directly quantify the load on the neck extensor and trapezius pars descendens muscles. The results for the level of muscle activity were also significantly affected by the change in screen height. The decreasing EMG activities of the neck extensor muscles affirm the improvement seen from the postural reactions to the increase in the screen height.

The minimum (3.3% of MVC) and maximum (18.6% of MVC) load recorded for the neck extensor muscle was highest at the screen height of 80 cm. These loads were lower at screen heights of 100 cm (minimum: 3.3% of MVC; maximum: 12.9% of MVC) and 120 cm (minimum: 1.6% of MVC; maximum: 8.7% of MVC). If these levels are compared to the acceptable static load for long-term work that is 2–5% of the MVC[24], then muscle fatigue will develop faster and more severely as the screen height is decreased. However, direct comparison with other results must be made with caution. The maneuvers used in this experiment may not be ideal to maximally activate the muscles tested. It may also be of worth to note that visual demands may modify the degree of activation of the muscles. Since the task performed in this experiment required constant visual monitoring, immobility at a flexed neck position may have generated greater muscle tension. Nonetheless, the trend of increasing muscle activity with the degree of adverse posture is consistent with the findings of other authors[2, 5, 18].

Interindividual differences in the activation of the muscles to changes in posture were shown to exist. The neck extensor muscle for all subjects decreased with the decrease in neck flexion. These results are in agreement with the findings of Schüldt *et al.*[18], Hamilton[5], Colombini *et al.*[2] However, the relationship between trunk inclination and trapezius muscle activity is less straightforward. Though in 6 out of 10 subjects stooping or forward-leaning was shown to activate the trapezius muscle more than with a backward-leaning trunk, in 2 subjects which showed otherwise a reclining trunk might mean an increase in muscle tension from shoulder flexion reaching for the mouse on the table. This postural adjustment cannot be measured using the methodology employed in the present study.

Conclusion

The placement of the screen is a significant factor effecting changes in the posture. A relatively upright posture results from an increase in the vertical location of the VDT screen. From the biomechanical point of view, the more upright position of the neck may result in the decreased load on the neck extensor muscles. This is manifested by the strong significant correlation between neck flexion and neck extensor muscle activity. On the other hand, shoulder load cannot be accurately predicted by trunk orientation in the frontal plane alone. The motions in the other axes should be considered. Also noted was the presence of interindividual differences in the recorded muscle activities that are greater than in the observed posture.

The present study emphasized the role of the workstation design in the dictating the postural adjustments to be made and the subsequent level of muscle activation. Nonetheless, the role of other components of the work system should not be ignored.

References

1) Laville A (1980) Postural reactions related to activities on VDU. In: Ergonomic aspects of visual display terminals. eds. by Grandjean E, Vigliani E, 167–74, Taylor & Francis, London.
2) Colombini D, Occhipinti E, Frigo C, Pedotti A, Grieco A (1986) Biomechanical, electromyographical and radiological study of seated postures. In: The ergonomics of working postures: models, methods and cases. eds. by Corlett N, Wilson J, Manenica I, 331–44, Taylor & Francis, London.
3) Nakaseko M, Morimoto K, Tanaka H (1993) An image analyzing approach to working postures for screen and keyboard use of visual display units. In: Work with display units 92. eds. by Luczak H, Cakir A, Cakir G, 235–9, Elsevier, Amsterdam.
4) Villanueva MBGV, Sotoyama M, Jonai H, Takeuchi Y, Saito S (1996) Adjustments of posture and viewing parameters of the eye to changes in the screen height of the visual display terminal. Ergonomics, **39**, 933–45.
5) Hamilton N (1996) Source document position as it affects head position and neck muscle tension. Ergonomics, **39**, 593–610.
6) Van der Heiden GH, Bräuninger U, Grandjean E (1984) Ergonomic studies on computer aided design. In: Ergonomics and health in modern offices. ed. by Grandjean E, 119–28, Taylor & Francis, London.
7) Ardnt R (1983) Working posture and musculoskeletal problems of video display terminal operators—review and appraisal. Am Ind Hyg Assoc J **44**, 437–46.
8) Bergqvist U, Wolgast E, Nilsson B, Voss M (1995) Musculoskeletal disorders among visual display terminal workers: individual, ergonomic, and work organizational factors. Ergonomics, **38**, 763–76.
9) Chaffin DB (1973) Localized muscle fatigue—definition and measurement. J Occup Med **15**, 346–54.
10) Hagberg M (1984) Occupational musculoskeletal stress and disorders of the neck and shoulder: a review of possible pathophysiology. Int Arch Occup Environ Health **53**, 269–78.
11) Kilbom Å, Persson J, Jonsson B (1986) Risk factors for work-related disorders of the neck and shoulder—with special emphasis on working postures and movements. In: The ergonomics of working postures: models, methods and cases. eds. by Corlett N, Wilson J, Manenica I, 44–53, Taylor & Francis, London.
12) Kumar S, Scaife WGS (1979) A precision task, posture and strain. J Safety Res **11**, 28–36.
13) Snijders CJ, Hoek van Dijke GA, Roosch ER (1991) A biomechanical model for the analysis of the cervical spine in static posture. J Biomechanics **24**, 783–92.
14) Sauter S, Schleifer L, Knutson S (1991) Work posture, workstation design and musculoskeletal discomfort in a VDT data entry task. Human Factors **33**, 151–67.
15) Maeda K (1977) Occupational cervicobrachial disorder and its causative factors. J Human Ergology **6**, 193–202.
16) Hagberg M (1995) The "mouse-arm" syndrome—concurrence of musculoskeletal symptoms and possible pathogenesis among VDU operators. In: Work with display units 95. eds. by Grieco A, Molteni B, Piccoli B, Occipinti E, 381–5, Elsevier, Amsterdam.
17) De Wall M, Van Riel MPJM, Aghina JCFM, Burdorf A, Snijders CJ (1992) Improving the sitting posture of CAD/CAM workers by increasing VDU monitor working height. Ergonomics **35**, 427–36.
18) Schüldt K, Ekholm J, Harms-Ringdahl K, Németh G, Arborelius U (1986) Effects of changes in sitting work posture on static neck and shoulder activity. Ergonomics **29**, 1525–37.
19) Japanese Industrial Standard S 1010–1978 (1993) Standard size for writing desks for office. Japanese Standards Association, Tokyo.
20) Sotoyama M, Villanueva MBG, Jonai H, Saito S (1995) Ocular surface area as an informative index of visual ergonomics. Ind Health **33**, 43–56.
21) Andersson B, Ortengreen R (1974) Lumbar disc pressure and myoelectric back muscle activity. Scand J Rehabilitation Med **3**, 115–21.
22) Caillet R (1981) Shoulder pain,. 2nd ed. 38–53, FA Davis, Philadelphia.
23) Järvholm U, Palmerud G, Karlsson D, Herberts P, Kadefors R (1990) Intramuscular pressure and electromyography in four shoulder muscles. J Orthop Res **9**, 609–19.
24) Jonsson B (1982) Measurement and evaluation of local muscular strain in the shoulder during constrained work. J Human Ergology **11**, 73–88.