A Survey of Physical Fatigue during Use of a Tablet LCD Monitor

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ABSTRACT

This paper describes an investigation of the fatigue awareness of different parts of the body and operational performance when using a tablet LCD monitor tilted at various angles. The results showed that the shoulder, wrist, forearm, and upper arm experienced the most fatigue while the elbow experienced the least. The fatigue awareness of the neck, back, and waist had the highest levels when the tablet LCD monitor was placed horizontally. An angle of 25° from the horizontal was the most comfortable for users and was the angle that users were most willing to use in the future. Gender had no obvious effect on fatigue level, comfort level, future willingness to use, and operational performance. However, the tilt angle of the monitor had a significant effect on fatigue level, comfort level and future willingness to use, but had no significant effect on operational performance.

Keywords: tablet LCD monitor, tilt angle, fatigue awareness, operational performance

手寫液晶螢幕使用時之身體疲勞度探究

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摘　　要

本研究針對手寫液晶螢幕在各種傾斜角度下操作時之身體各部位的疲勞度及操作績效進行探究。研究結果顯示，以「肩膀」、「手腕」、「前臂」、「上臂」這四個部位之疲勞度較高，「手肘」則最低，而「背部」及「腰部」之疲勞度亦不高；此外，在螢幕平放(0°角)時，「脖子」、「背部」及「腰部」這三個部位之疲勞度反而較在其他螢幕角度之疲勞度為高；螢幕於25度傾斜角為使用者感覺身體舒適度最好的繪圖角度，同時也是使用者未來採用意願最高的角度；性別對疲勞度、整體舒適度、未來使用意願及操作績效沒有顯著影響；然而，螢幕傾斜角度卻對疲勞度、整體舒適度及未來使用意願有顯著影響，惟對操作績效沒有顯著影響。

關鍵詞：手寫液晶螢幕，傾斜角度，疲勞度，操作績效

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I. INTRODUCTION

The advance of technology has led to the computer becoming a very important tool in the design process. Using computers to create drawings not only increases the quality of the design but also significantly reduces the time required to complete the design. However, despite the advanced state of computer drawing technology, users still require input devices to operate the computer.

The development of computer input devices has kept pace with the general development of technology in trying to make the input process more direct and natural for users. The pen-based graphics tablet (also referred to as a digitizing tablet, graphics pad, and drawing tablet) was invented to reduce the inconvenience of drawing using a traditional mouse. A graphics tablet consists of a flat surface upon which the user may "draw" an image using a pen-like drawing device called a stylus. The image generally does not appear on the tablet itself but is more often displayed on a computer monitor. The main advantage of the graphics tablet is that it provides a much more intuitive way of creating more natural-looking freehand graphics than other input devices such as the mouse, because graphics tablets simulate pen and paper. In addition, "Graphics tablets are an excellent alternative to the ubiquitous mouse for computer users looking for more-precise cursor control, or battling repetitive stress injuries" [1].

However, because the image generally does not appear on the tablet itself during the drawing process, users cannot see both the image and hand movement simultaneously. As a result, users cannot move the pen directly to the desired location quickly and precisely, making the tablet still somewhat inconvenient [2]. This problem has been solved by the successful development of the tablet liquid crystal display (LCD) monitor, sometimes referred to as the graphics tablet/screen hybrid or the tablet/LCD hybrid. A tablet LCD monitor is a graphics tablet that incorporates an LCD in the tablet itself, allowing the user to draw directly on the display surface with a pressure-sensitive digital pen (Fig. 1) and to see the location of the pen directly on the image, on the screen. "Working directly with the pen on screen allows users to work faster and more naturally because of the intuitive hand-eye coordination" [3]. Therefore, drawing directly on the screen will become increasingly important in the design industry.

Fig. 1. Operation of a tablet LCD monitor (from the WACOM website).

One problem with computers is the requirement for frequent and repetitive hand movements, especially when using traditional input devices such as the keyboard or mouse. Drawing for long periods with a mouse or maintaining an inappropriate posture may cause musculoskeletal disorders [4-6] and is harmful to the human body. Carpal tunnel syndrome is one of the most serious and frequent of those musculoskeletal disorders [7-10]. That is why much research has been conducted into posture while using a mouse and the workload burden placed on the human body [11-16].

The digital pen can be used to accomplish the same tasks as the mouse, and it can be moved as easily as the mouse [17]. "Using a pen means that several muscles in the fingers, hand, and arm are being used evenly; with most mice, the same muscles in the fingers, hand, and arm are used and then rest in the same position for a longer time" [18]. Furthermore, pen use results in a posture that is more neutral than that during mouse use. Therefore, the pen appears to be a biomechanically superior input device [19].

Hedge and Chao [20] compared the wrist posture (ulnar/radial flexion/extension; wrist pronation/supination) required to use two pen-shaped mice and a conventional mouse, and found that the pen-shaped mice reduced wrist pronation and ulnar deviation while increasing wrist extension, as compared to a conventional mouse design. Kotani and Horii [21] observed that pen-tablet usage reduced the overall muscular load or activity of the arm and also reduced the stress on the fingers, but did not reduce the stress due to stabilizing the upper arm when compared to a conventional mouse input system. Of the four muscles evaluated in that study, the trapezius showed the highest muscular activity for both input devices. This implies that the pen-based input device could not directly reduce the postural load generated by supporting the forearm and the wrist.

Although, according to the above mentioned, it seems that pen-based input using a tablet LCD monitor is more ergonomic than traditional mouse input and can reduce the harm to the wrist, problems still exist. Fatigue is frequently cited as an undesirable side effect of pointing over a display [22]. Fatigue can be caused by the need to apply pressure to maintain selections [23]. Fatigue may also occur due to the thickness of the monitor, which makes it impossible to place the wrist and forearm horizontally when the monitor is horizontal. Additionally, reflection from the monitor may require users to adjust the monitor to a certain angle to avoid eye strain, but this may also cause the wrist, forearm, elbow, or even the upper arm and shoulder to experience fatigue.

Existing literature is mostly oriented to the medical issues related to the use of hand tools such as pens. Even so, no reports could be found of a general study of the effects of tablet LCD monitor operating angle on operational performance and level of fatigue in different body parts. These issues should be investigated. Such an investigation would lead to a better understanding of the operation of tablet LCD monitors.

The purpose of this study was to investigate the fatigue awareness of different parts of the body, comfort level, future willingness to use and operational performance at different tablet LCD monitor tilt angles in order to provide valuable operating suggestions for designers selecting this input device for use, and to provide a useful reference for the future development of tablet LCD monitors.

II. METHODS

In this study, a tablet LCD monitor was used as the experimental device. First, the participants were asked to complete a drawing task by tracing a sample drawing shown on the monitor at each test tilt angle; the time taken to complete this task was recorded. After the participants completed the drawing task at each tilt angle, they were asked to fill out a pen-and-paper questionnaire to indicate the fatigue levels in different parts of the body, the overall comfort level, and the willingness to use the monitor again at the same angle. The aim was to determine the best angle to provide a reference for the future use of this kind of product.

2.1 Participants

All 32 voluntary participants were students from the Design School at Ming Chuan University; 16 were male and 16 were female. Their ages were between 20 and 26 years (*M*=23.1years). They were all right-handed, in good health, and had basic user experience with computer hardware and software. However, none of the participants had ever used a tablet LCD before.

2.2 Apparatus

The Wacom Cintiq 21UX Interactive Pen Display and Corel Painter graphic software package were used for the drawing tasks. The Cintiq 21UX is a tablet LCD monitor with 21.3 inch diagonal size, 0.27 mm dot pitch / pixel pitch, 1600 x 1200 pixels resolution and 1024 levels of pressure sensitivity. In addition, “the Cintiq 21UX has a dynamically adjustable stand that allows the user to rotate the display up to 180° in each direction, incline the display from 10° to 65°, and even remove it for comfortable lap use” [24].

2.3 Sample Drawing Used for the Experiment

To ensure that the participants experienced physical fatigue during the drawing process, the sample drawing shown in Fig. 2 was designed to have many lines and time-consuming patterns, and requires the use of strokes similar to drawing motions.

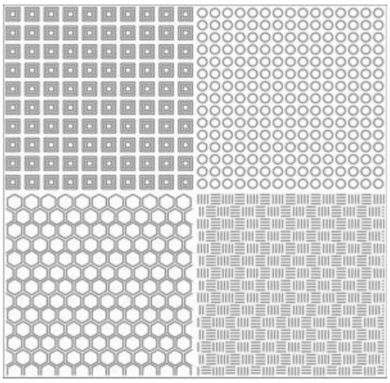

Fig. 2. Sample drawing used for the drawing task.

2.4 Questionnaire

The questionnaire had two parts. The first part was the subjective rating of the fatigue level of the ten different body parts more likely affected by the drawing task shown in Fig. 3. The second part of the questionnaire contained the subjective ratings of the overall comfort level and willingness to use the device again for each angle. The participants marked their evaluations on a seven-point scale where 1 indicated the least perceived fatigue, lowest comfort level, or least willingness to use the device again at that angle.

2.5 Experimental Protocol

Six tilt angles (Fig. 4) were tested: 0°, 10°, 25°, 40°, 55°, and 65° from the horizontal. The participants were asked to use the experimental device to trace the sample drawings displayed on the monitor at each tilt angle. After the participants completed the drawing task, they filled out the questionnaire rating fatigue levels of the ten body parts, their overall level of comfort, and their willingness to use the device at the same angle again, all on a scale of 1–7.

The participants were informed in advance about the purpose of the experiment and the procedure to be used so that the experiment would run smoothly. They were then instructed sit down and adjust the height of the chair to a suitable position in front of the monitor which was placed on a 73cm high table and was about 50cm from the body. They picked up the pen in one hand and placed their elbows on the table in their most natural drawing posture. The time spent completing the drawing task at each tilt angle was recorded; the time required to start the software and settle down were not included. Corel Painter was used for the drawing task with the drawing window open to full screen size and set to draw as a thick black pen, the same width of the line weight in the sample drawing. The participants were simply told to react as though they had been given a black pen to trace the sample drawing.

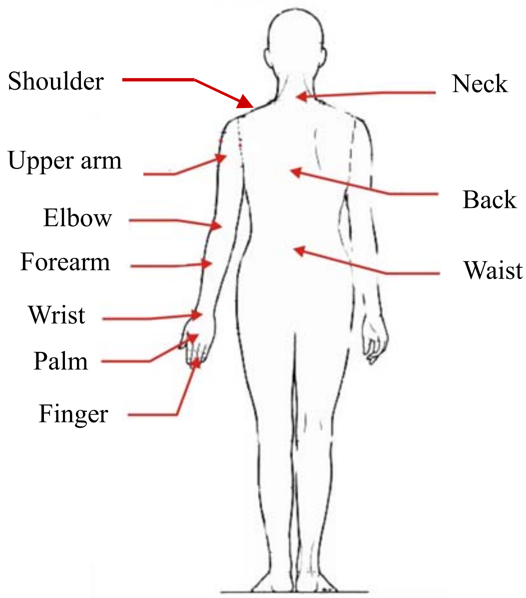

Fig. 3. Body parts rated for the level of fatigue.

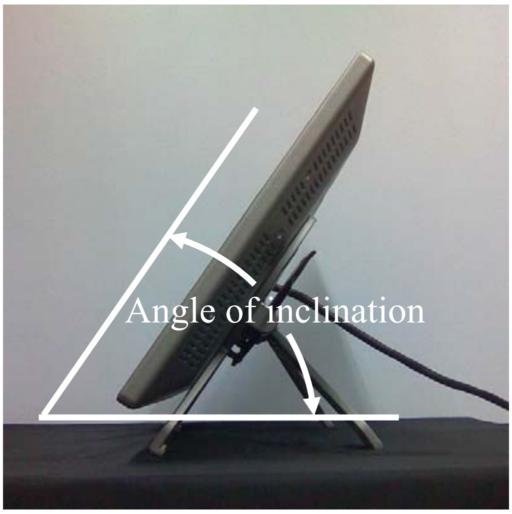

Fig. 4. Monitor angle of inclination.

To ensure the consistency and reliability of the experiment, the participants had to continue drawing without resting until the drawing task was complete. After completing each task, the participants were asked to fill out the subjective questionnaire immediately, according to their experience in that task.

One monitor tilt angle was tested with each participant per day, i.e., the complete experiment took each participant six days to complete. The angle tested on any given day was a completely random selection from those that had not yet been tested. The purpose of the randomized sequence and the prolonged time between different angles was to increase the reliability of the experiment and the questionnaire responses, reducing any possible influences like being familiar with the operation or previous impressions. In addition, every participant sat in the same place and used the same device to ensure that the experimental environment was identical and to exclude any irrelevant variables.

2.6 Statistical Analyses

Descriptive statistics were performed on the mean duration time to complete the drawing task (i.e., operational performance) and on the data collected from the questionnaire at the six different inclination angles. Difference analyses were also performed using the *t*-test and one-way ANOVA with LSD (Least Significant Difference) post-hoc test on the data to determine if there were any significant differences in fatigue levels, operational performance, overall level of comfort, and future willingness to use due to gender and monitor tilt angle, respectively. In addition, correlation analysis was performed as well in an effort to identify the relationship among overall level of fatigue, overall level of comfort, future willingness to use, and operational performance. These analyses were conducted using the SPSS statistical software package. Significance was noted for the probability of a false positive being less than 5% (i.e., α=0.05).

III. RESULTS

3.1 Fatigue Levels

Table 1 shows the participants' awareness of the fatigue levels in different parts of their bodies and the results of the difference analysis according to the *t*-test between males and females at the six different operating angles. From Table 1 it can be found that female participants tended to feel fatigue more easily than males. However, the results of the *t*-test showed that, except for the forearm at 0°, where a significant difference was observed (p <0.05), there was no significant difference between males and females. This indicates that gender had very little significant effect on fatigue awareness.

Fig. 5 shows the distribution of the fatigue level of the ten body parts of all participants as a function of angle. The participants experienced most fatigue in the shoulder, wrist, forearm, and upper arm, more fatigue in the finger, palm, and neck, less fatigue in the back and waist, and the least fatigue in the elbow.

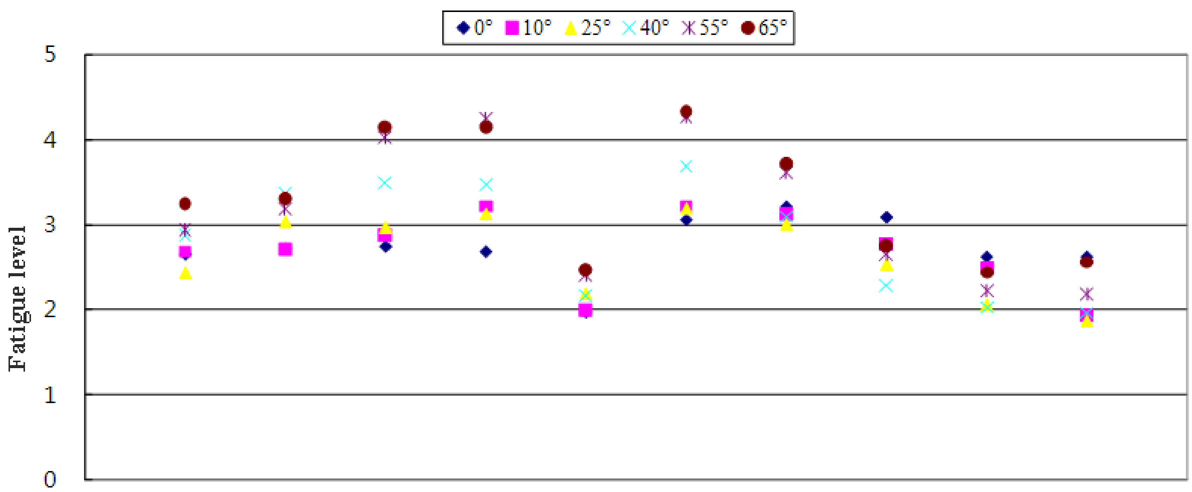

Fig. 5. Distribution of fatigue levels of the ten body parts as a function of monitor tilt angle.

Table 1. Mean (SD) fatigue levels★ of the ten body parts at different monitor tilt angles

Inclination (deg)	Gender/ *t*-test	Finger	Palm	Wrist	Fore-arm	Elbow	Upper arm	Shoulder	Neck	Back	Waist
0	Total	2.66 (1.94)	2.72 (1.53)	2.75 (1.48)	2.69 (1.40)	1.97 (1.58)	3.06 (1.29)	3.22 (1.58)	3.09 (1.71)	2.62 (1.62)	2.62 (1.72)
	Male	2.31 (1.85)	2.38 (1.20)	2.38 (1.02)	2.19 (0.98)	1.50 (1.10)	2.69 (1.30)	3.44 (1.75)	3.19 (1.97)	2.50 (1.55)	2.44 (1.63)
	Female	3.00 (2.03)	3.06 (1.77)	3.13 (1.78)	3.19 (1.60)	2.44 (1.86)	3.44 (1.21)	3.00 (1.41)	3.00 (1.46)	2.75 (1.73)	2.81 (1.83)
	Sig. p☆	0.325	0.209	0.158	**0.041***	0.095	0.102	0.443	0.762	0.670	0.546
10	Total	2.69 (1.76)	2.72 (1.42)	2.88 (1.31)	3.22 (1.45)	2.00 (1.46)	3.22 (1.21)	3.13 (1.45)	2.78 (1.39)	2.50 (1.39)	1.94 (0.91)
	Male	2.31 (1.58)	3.00 (1.41)	2.94 (1.29)	2.94 (1.29)	1.69 (1.08)	3.13 (1.20)	3.06 (1.48)	2.69 (1.58)	2.38 (1.45)	1.88 (1.02)
	Female	3.06 (1.94)	2.44 (1.41)	2.82 (1.38)	3.50 (1.59)	2.31 (1.74)	3.31 (1.25)	3.19 (1.47)	2.88 (1.20)	2.63 (1.36)	2.00 (0.82)
	Sig. p	0.241	0.269	0.793	0.281	0.233	0.669	0.812	0.708	0.619	0.705
25	Total	2.44 (1.58)	3.03 (1.49)	2.97 (1.56)	3.13 (1.50)	2.19 (1.51)	3.19 (1.26)	3.00 (1.48)	2.53 (1.39)	2.06 (1.08)	1.88 (0.91)
	Male	2.13 (1.31)	3.06 (1.44)	2.75 (1.29)	2.69 (0.87)	1.81 (1.22)	2.94 (1.12)	2.81 (1.38)	2.44 (1.59)	1.88 (1.02)	1.75 (0.86)
	Female	2.75 (1.81)	3.00 (1.59)	3.19 (1.80)	3.565 (1.86)	2.56 (1.71)	3.44 (1.36)	3.19 (1.60)	2.62 (1.20)	2.25 (1.13)	2.00 (0.97)
	Sig. p	0.272	0.908	0.435	0.103	0.165	0.267	0.483	0.710	0.332	0.445
40	Total	2.88 (1.93)	3.38 (1.81)	3.50 (1.78)	3.47 (1.65)	2.16 (1.46)	3.69 (1.31)	3.09 (1.57)	2.28 (1.11)	2.03 (1.15)	1.97 (1.18)
	Male	2.94 (1.88)	3.38 (1.54)	3.13 (1.15)	3.56 (1.41)	2.00 (1.26)	3.56 (1.09)	3.06 (1.53)	2.25 (1.29)	1.88 (1.20)	1.56 (0.81)
	Female	2.81 (2.04)	3.38 (2.09)	3.88 (2.22)	3.38 (1.89)	2.31 (1.66)	3.82 (1.52)	3.13 (1.67)	2.31 (0.95)	2.19 (1.11)	2.38 (1.36)
	Sig. p	0.858	1.000	0.242	0.753	0.554	0.596	0.913	0.877	0.451	0.051
55	Total	2.94 (1.68)	3.19 (1.93)	4.03 (1.67)	4.25 (1.32)	2.41 (1.58)	4.28 (1.30)	3.63 (1.43)	2.66 (1.10)	2.22 (1.31)	2.19 (1.40)
	Male	2.81 (1.60)	3.19 (1.68)	3.81 (1.47)	4.44 (1.26)	2.31 (1.45)	4.38 (1.45)	3.44 (1.41)	2.69 (1.25)	2.06 (1.18)	1.94 (1.18)
	Female	3.06 (1.81)	3.19 (2.20)	4.25 (1.88)	4.06 (1.39)	2.50 (1.75)	4.19 (1.17)	3.81 (1.47)	2.63 (0.96)	2.38 (1.45)	2.44 (1.59)
	Sig. p	0.682	1.000	0.469	0.431	0.744	0.690	0.468	0.875	0.510	0.321
65	Total	3.25 (1.87)	3.31 (1.73)	4.16 (1.51)	4.16 (1.42)	2.47 (1.87)	4.34 (1.62)	3.72 (1.49)	2.75 (1.59)	2.44 (1.54)	2.57 (1.78)
	Male	3.13 (1.86)	3.69 (1.92)	4.00 (1.41)	4.25 (1.39)	2.38 (1.67)	4.44 (1.67)	3.63 (1.15)	2.75 (1.53)	2.38 (1.41)	2.44 (1.67)
	Female	3.38 (1.93)	2.94 (1.48)	4.31 (1.62)	4.06 (1.48)	2.56 (2.10)	4.25 (1.61)	3.81 (1.80)	2.75 (1.69)	2.50 (1.71)	2.69 (1.92)
	Sig. p	0.711	0.226	0.566	0.715	0.781	0.749	0.727	1.000	0.823	0.697

★Rated on a scale of 1–7.
☆ To determine if there were significant differences between males and females; two-tailed.
* Denotes a significant difference at $p < 0.05$.

Fig. 6 shows the distribution of the fatigue levels of the ten body parts at six different tilt angles for the males alone, the females alone, and all the participants together. The figures show that the fatigue level of the finger decreased slowly with increasing tilt angle; it reached a minimum value at about 25° and then began to increase with increasing tilt angle. The

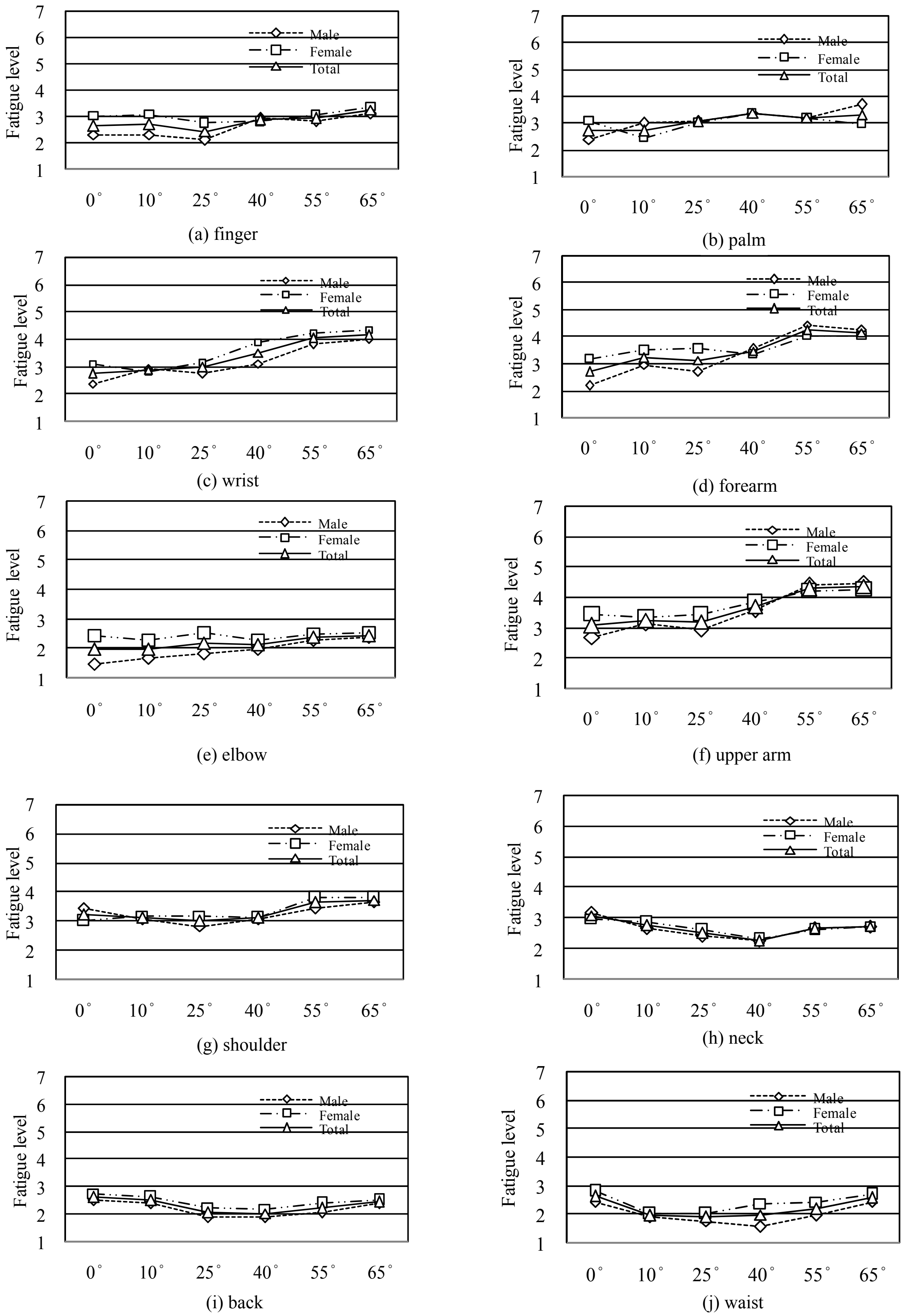

Fig. 6. Fatigue level of the ten body parts for different monitor tilt angles.

fatigue levels of the palm, wrist, forearm, and upper arm increased gradually with increasing tilt angle but started to increase more sharply beyond 25°. The fatigue level of the elbow increased slightly with increasing tilt angle over the whole range. The fatigue levels of the shoulder, neck, back, and waist decreased with increasing tilt angle and reached a minimum value at about 25°–40°, and then increased with increasing tilt angle. However the fatigue levels of the neck, back, and waist were maximum at 0°.

In summary, although the fatigue levels of the different body parts varied with the monitor tilt angle, the following tendencies were observed and supported by ANOVAs (as shown in Table 2). The fatigue levels were not significantly affected by the tilt angle of the monitor below 25°; however, the fatigue levels of the body parts increased with increasing tilt angle above 25° and, in this range, the tilt angle had a significant effect on the fatigue levels of the wrist (p<0.001), forearm (p<0.001), and upper arm (p<0.001). Multiple comparisons with the least significant difference (LSD) method showed that the fatigue levels at 0°, 10° and 25° were significant lower than those at 55° and 65° for the wrist, forearm and upper arm, and 0° was also significant lower than 40° for the forearm (as shown in Table 2).

Table 2. ANOVA for mean fatigue levels at different monitor tilt angles

	F value	*P* value	LSD post-hoc test
Finger	0.770	0.573	—
Palm	0.958	0.445	—
Wrist	4.908	0.000*	0°, 10°, 25°<55°, 65°
Forearm	4.908	0.000*	0°<40°, 55°, 65° ; 10°, 25°<55°, 65°
Elbow	0.537	0.748	—
Upper arm	5.809	0.000*	0°, 10°, 25°<55°, 65°
Shoulder	1.278	0.275	—
Neck	1.204	0.309	—
Back	1.029	0.402	—
Waist	1.865	0.102	—

*Significant at 0.001 level.

3.2 Overall Level of Comfort, Future Willingness to Use, and Operational Performance

3.2.1 Overall Level of Comfort

Table 3 shows the participants' awareness of the overall level of comfort at the six different operating angles and the results of the difference analysis according to the t-test between males and females. From Table 3 it can be found that the angle with the best overall level of comfort was 25° (M = 5.53), and the worst was 65° (M = 2.63). The results for males and females were not significantly different according to the t-test.

Fig. 7 shows that the overall level of comfort increased with increasing tilt angle from 0°, reached a maximum at about 25°, and then decreased with increasing tilt angle greater than 25°. The results of the difference analysis according to the ANOVA (as shown in Table 4) for the six different operating angles showed that the overall level of comfort was significantly affected by the tilt angle of the monitor (p<0.001). Multiple comparisons with the LSD method showed that the comfort levels at 0°, 10° and 25° were significant higher than those at 55° and 65°, 10° and 25°were significant higher than 40°, and 25° was also significant higher than 0° (as shown in Table 4). This shows that participants did not feel more comfortable when the monitor was closer to the horizontal or vertical positions.

Table 3. Overall level of comfort★ at different monitor tilt angles

Inclination (deg)	Male (n=16)		Female (n=16)		Total (n=32)		*Sig. p*☆ (2-tailed)
	Mean	SD	Mean	SD	Mean	SD	
0	4.44	1.67	4.94	1.34	4.69	1.51	0.358
10	5.13	1.15	4.94	1.18	5.03	1.15	0.652
25	5.75	0.58	5.31	1.30	5.53	1.02	0.233
40	4.38	1.02	3.94	1.18	4.16	1.11	0.272
55	3.19	1.22	2.75	1.39	2.97	1.31	0.352
65	2.25	1.24	3.00	1.46	2.63	1.39	0.128

★ Rated on a scale of 1-7.
☆ To determine if there were significant differences between males and females.

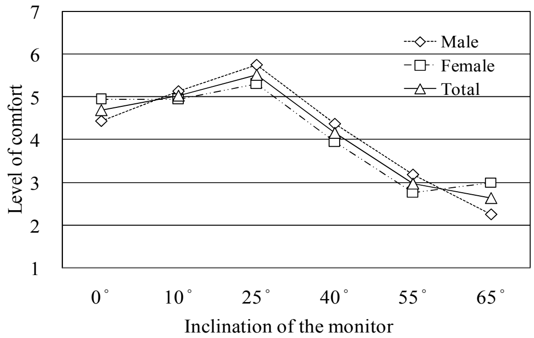

Fig. 7. Overall level of comfort for different monitor tilt angles.

Table 4. ANOVA for mean comfort levels, future willingness to use and operational performance at different monitor tilt angles

	F value	*P* value	LSD post-hoc test
Level of comfort	27.053	0.000*	0°< 25°, 0°>55°, 65° 10°, 25°>40°,55°, 65°
Future willingness to use	24.516	0.000*	0°, 10°, 40°>55°, 65° 25°>0°,40°,55°, 65°
Operational performance	1.318	0.258	—

*Significant at 0.001 level.

3.2.2 Future Willingness to Use

Table 5 shows that future willingness to use the device was the highest for an angle of 25° (M = 5.28) and lowest for 65° (M = 2.16). The results for male and female participants were similar, and the *t*-test revealed no significant difference between them. Fig. 8 shows that future willingness to use increased as the tilt angle increased from 0°, reached a peak at about 25°, and then decreased as the tilt angle increased even further. The results of the difference analysis according to the ANOVA (as shown in Table 4) for the six different operating angles showed that future willingness to use was significantly affected by the tilt angle of the monitor (p<0.001). Multiple comparisons with the LSD method showed that the future willingness to use at 0°, 10°, 25° and 40° were significant higher than that at 55° and 65°, and 25° was also significant higher than 0° and 40° (as shown in Table 4). This shows that participants prefer not to draw with the monitor placed closer to the vertical or horizontal positions and, more especially, not the former.

Table 5. Future willingness to use★ in relation to different monitor tilt angles

Inclination (deg)	Male (n=16)		Female (n=16)		Total (n=32)		*Sig. p*☆ (2-tailed)
	Mean	SD	Mean	SD	Mean	SD	
0	4.25	1.88	4.75	1.44	4.50	1.67	0.405
10	4.88	1.41	4.69	1.66	4.78	1.52	0.733
25	5.38	0.89	5.19	1.17	5.28	1.02	0.612
40	4.25	1.44	4.19	1.56	4.22	1.48	0.907
55	2.81	1.38	2.44	1.63	2.63	1.50	0.488
65	1.88	1.31	2.44	1.26	2.16	1.30	0.226

★ Rated on a scale of 1-7.
☆ To determine if there were significant differences between males and females.

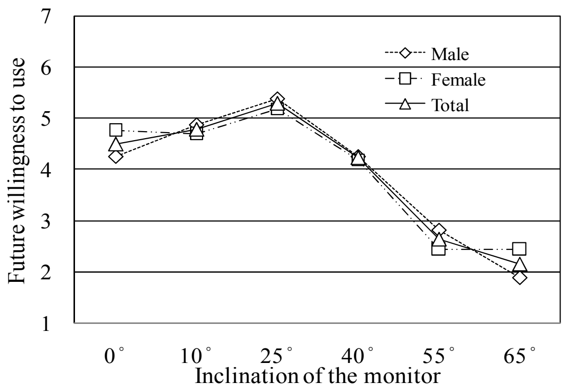

Fig. 8. Future willingness to use in relation to different monitor tilt angles.

3.2.3 Operational Performance

The operational performance was defined as the time required to complete the drawing task. The more the time required, the less the operational performance is. The results in Table 6 show that for all the participants, the most time-consuming angle was 65° (1059 s) and the least time-consuming was 0° (908 s). Fig. 9 shows that the operational performance decreased with increasing tilt angle starting from 0°. The difference of time increase was small between 0° and 40°, and larger for angles greater than 40°. The time required by female participants increased as the tilt angle increased. This was slightly different for males, who required the least time at 25°. However, the *t*-test showed that these differences were not significant (Table 6). In addition, the results of the difference analysis according to the ANOVA (as shown in Table 4) for the six different operating angles also showed that operational performance was not significantly affected by the tilt angle of the monitor ($p>0.05$).

Table 6. Mean time for completing the drawing task at different monitor tilt angles

Inclination (deg)	Male (n=16)		Female (n=16)		Total (n=32)		*Sig. p*☆ (2-tailed)
	Mean time (s)	SD	Mean time (s)	SD	Mean time (s)	SD	
0	929	268	888	264	908	263	0.667
10	934	239	920	278	927	255	0.878
25	914	213	948	311	931	263	0.721
40	940	232	955	295	948	261	0.878
55	993	262	990	316	992	286	0.979
65	1079	306	1038	329	1059	310	0.709

☆ To determine if there were significant differences between males and females.

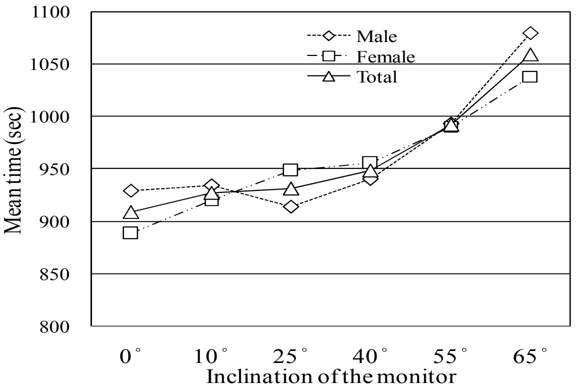

Fig. 9. Mean time for completing the drawing task at different monitor tilt angles.

IV. DISCUSSION

The tablet LCD monitor is a new input device on which one can draw directly with a digital pen, very much like traditional drawing. It is more convenient for designers to draw and communicate ideas in a natural comfortable way, and results in output products closer to the original design. The tablet LCD monitor has many advantages over other input devices. The tablet LCD monitor has been used by an increasing number of designers and companies, following the trend of paperless design. It is a device with a promising future.

The shoulder, wrist, forearm, and upper arm were the four parts of the body with the highest levels of fatigue awareness, after drawing at all the angles tested. This result is consistent with the study by Kotani and Horii [21], which showed that the trapezius experienced the highest muscular load when using the pen-tablet input device. This indicates that pen-based input devices cannot directly reduce the postural load generated by supporting the forearm and the wrist. Furthermore, the elbow experienced the lowest level of fatigue. However, the fatigue awareness of the neck, back, and waist had the highest levels when the tablet LCD monitor was placed horizontally.

We might think that having the monitor in a horizontal position, to emulate the actual use of pen and paper, would be the preferred position. However, although the results showed that the operational performance using the horizontal monitor was better than that of the other tilt angles, the highest levels of overall comfort and future willingness to use occurred at 25°, not 0°, and were significantly higher than those at 0°. This means that users prefer angles other than the horizontal. This result is also consistent with the study by Schüldt et al. [25], which showed that a tilted work surface was preferable to one that is vertical or horizontal. The reason why 0° is not the most preferred angle can be explained by the fatigue awareness of the body at different tilt angles. At 0°, the palm, wrist, forearm, elbow, and upper arm had the lowest fatigue levels while the neck, back, and waist had the highest fatigue levels. At 25°, however, the finger, shoulder, and waist had the lowest fatigue levels of all the angles, and no other body part experienced its highest fatigue level at this angle.

From the results mentioned earlier and summarized in Table 7, it is clear that the trend distributions of overall level of comfort and future willingness to use at different tilt angles were similar, and a significant positive correlation exists (as shown in Table 8). However, these two trends appeared in the opposite direction to that of the fatigue levels of the body parts, i.e., a significant negative correlation exists (as shown in Table 8). This result is consistent with the general recognition that a lower fatigue level means a greater level of overall comfort and a greater willingness to use the device in the future. This indicates that the results of this study are highly consistent. In addition, the trend of the time required to complete the drawing task, which increased with increasing tilt angle, was different from that of the overall average fatigue level of the body parts, which decreased with increasing tilt angles between 0° and 25°, but they were the same after 25° (Table 7). This discrepancy exists because angles less than 25° caused fatigue to increase only in the shoulder, neck, back, and waist, which have minor effects on drawing speed. Under the same conditions, the fatigue levels of most parts of the hand appeared to decrease (Fig. 6).

Table 7. Summary of results

Inclination (deg)	Average fatigue level*(n=32)	Mean comfort level (n=32)	Mean willingness to use (n=32)	Mean time (s) (n=32)
0	2.74	4.69	4.50	908
10	2.71	5.03	4.78	927
25	2.64	5.53	5.28	931
40	2.84	4.16	4.22	948
55	3.18	2.97	2.63	992
65	3.32	2.63	2.16	1059

* Average value of the fatigue levels of the ten body parts.

Although differences between males and females were observed in the fatigue level, the overall level of comfort, the future willingness to use, and the time required to complete the assigned drawing task, the only statistically significant difference existed for the upper arm at 0° (*p* is only 0.041, so it could be by chance). This indicates that gender had no obvious effect on fatigue level, overall level of comfort, future willingness to use, and operational performance. However, according to the above mentioned results, the tilt angle of the monitor had a significant effect on fatigue level, comfort level and future willingness to use, but had no significant effect on operational performance.

Table 8. Pearson correlation analysis results

	Average Fatigue level	Comfort level	Willingness to use	Time required (Operational performance)
Average Fatigue level	1.00			
Comfort level	-.985**	1.00		
Willingness to use	-.996**	.992**	1.00	
Time required	.942**	-.884*	-.909*	1.00

*Significant at 0.05 level (two-tailed).
**Significant at 0.01 level (two-tailed).

V. CONCLUSION

An angle of about 25° was the most preferred drawing angle, based on the overall level of comfort and the future willingness to use. The operational performance at this angle was not much different than that at 0°. Therefore, adjusting the tablet LCD monitor to about 25° would be the best choice, taking into account both the level of overall comfort and the operational performance. In addition, when the monitor was used between 0° and 25°, the operational performance, overall level of comfort, and the future willingness to use were also good. An angle between 25° and 40° was tolerable, but angles greater than 40° should be avoided for long-term use.

The tablet LCD monitor is an increasingly popular product. There are still many ergonomic issues, such as monitor brightness, depth, and the arrangement of buttons around the monitor, that merit further study. In addition, this study examined the effect of only a small number of tilt angles; this could be expanded in future studies.

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