The Effect of Thickness on the Operation of a Tablet Monitor

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ABSTRACT

With more and more improvements in volume, weight, function and operation way, tablet monitors have already become a new useful tool for designers. This study describes an investigation of the fatigue awareness of different parts of the body, comfort level and operational performance when using a tablet monitor at various thicknesses. Thirty-five participants were recruited. Seven thicknesses were tested by using a thickness changeable tablet monitor simulator as the experimental device. The results showed that the thickness had a significant effect on the fatigue awareness of the most body parts. In addition, the thickness also had a significant effect on comfort level, but had no significant effect on operational performance. Moreover, gender had no obvious effect on fatigue level, comfort level, and operational performance. Overall speaking, a thickness of about 10 mm was a suitable drawing thickness.

Keywords: tablet monitor, thickness, fatigue awareness, comfort level, operational performance

厚度對電腦繪圖螢幕操作之影響

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摘　　要

隨著體積、重量、功能與使用方式的不斷精進，繪圖螢幕已成為設計從業人員的一個有利新工具。本研究針對繪圖螢幕在各種厚度下操作時之身體各部位的疲勞度、舒適度及操作績效進行探究，共有 35 位受試者在可變化厚度的繪圖螢幕模擬器上進行了 7 種不同厚度狀況下之圖稿的描繪。結果顯示厚度對於身體諸多部位的疲勞度有顯著影響，厚度越大疲勞度就呈越大的趨勢，此外，螢幕厚度亦對整體舒適度有顯著影響，惟對操作績效卻沒有顯著影響。再者，性別對疲勞度、整體舒適度、及操作績效均沒有顯著影響。總的來說，適合的操作厚度約在 10 mm左右。

關鍵詞：繪圖螢幕，厚度，疲勞度，舒適度，操作績效

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I. INTRODUCTION

The advancement of computer technology has led design process into a digital design era. 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 pen-based graphics tablet (also referred to as a digitizer, digitizing tablet, graphics pad, pen tablet or drawing tablet) (Fig. 1) 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 or trace 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 [1]. The main merit 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 drawing tablets simulate pen and paper [2].

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 [3]. Fortunately, with the improvement of liquid crystal display techniques in recent years, this problem has been solved by the successful development of the tablet liquid crystal display (LCD) monitor, also referred to as the graphics tablet/screen hybrid, the tablet/LCD hybrid or the tablet monitor. A tablet 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. 2), which completely replaces the function of mouse and keyboard typing, 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” [4]. Therefore, drawing directly on the screen will become increasingly important in the design industry.

Fig. 1. Wacom’s pen tablet (from the WACOM website).

Fig. 2. Operation of a tablet monitor (from the ACCUSEE Technology Inc. website).

One problem with computers is that drawing for long periods with a mouse or maintaining an inappropriate posture may cause musculoskeletal disorders [5-7] and is harmful to the human body. That is why much research has been conducted into posture while using a mouse and the workload burden placed on the human body [8-13].

The digital pen can be used to accomplish the same tasks as the mouse, and it can be moved as easily as the mouse [14]. “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” [15]. 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 [16].

Although, pen-based input seems 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 [17]. Fatigue can be caused by the need to apply pressure to maintain selections [18]. 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.

According to the current products of the main computer drawing equipment manufacturers [19-21], it shows that the thicknesses of graphics tablets and tablet monitors are about between 8 to 28 mm and 16 to 64 mm, respectively. It also reveals that the thickness among them is quite different.

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 monitor or graphics tablet thickness on operational performance and level of fatigue in different body parts. Is it really the thinner the better for the level of fatigue of the body parts during use of tablet monitors or graphics tablets? These issues need to be investigated. Such an investigation would lead to a better understanding of the operation of tablet monitors or graphics tablets.

The purpose of this study was to investigate the fatigue awareness of different parts of the body, comfort level and operational performance at different tablet monitor thicknesses 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 monitors.

II. METHODS

In this study, a tablet monitor simulator (Fig. 3) was used as the experimental device. First, the participants were asked to complete a drawing task by tracing a sample drawing shown on the simulator at each test thickness; the time taken to complete this task was recorded. After the participants completed the drawing task at each thickness, they were asked to fill out a pen-and-paper questionnaire to indicate the fatigue levels in different parts of the body, and the overall comfort level.

In order to be consistent with traditional desk-drawing mode, the experiment of this study was carried out by placing the simulator in a horizontal position to emulate the actual use of pen and paper.

2.1 Participants

All 35 voluntary participants were students from the Design School at Ming Chuan University; 17 were male and 18 were female. Their ages were between 18 and 27 years (*M*=23.2years). They were mostly right-handed, in good health, and had basic user experience with computer hardware and software.

2.2 Apparatus

A tablet monitor simulator was used for the drawing tasks. The simulator was made by a transparent PVC sheet (A), a tracing paper (B), and a transparent acrylic board (C) (as shown in Fig. 3). The dimensions of the simulator are 422(W) x 342(D) x 6(H) mm. The tracing paper (B) printed with the sample drawing and with the size of 382x302 mm for simulating the screen size of a 19" monitor was placed between A and C, and was adhered on the C. It means that the distance between the rim of the tracing paper and the rim of the acrylic board is 20 mm each for the four sides. A black marker pen was used. The participants were asked to use the pen to draw on the transparent PVC sheet (A) by tracing the sample drawing.

In order to simulate an extreme condition, i.e., thickness is 0 mm, an ABS board (D) (as shown in Fig. 3) with the same thickness (i.e., 6 mm) of the simulator was placed on both sides of the simulator to keep the drawing condition the same as drawing on a paper. The other test thicknesses were adjusted by using wood plates, with cross sectional dimensions 10x10 mm, placed and fastened by twin adhesive beneath the simulator’s frame edge.

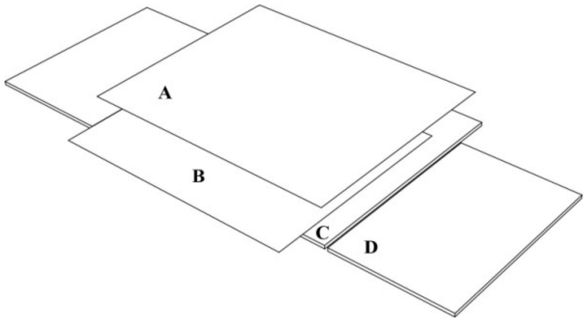

Fig. 3. Simulator used for the experiment.

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. 4 was designed to have many lines and time-consuming patterns, and requires the use of strokes similar to drawing motions.

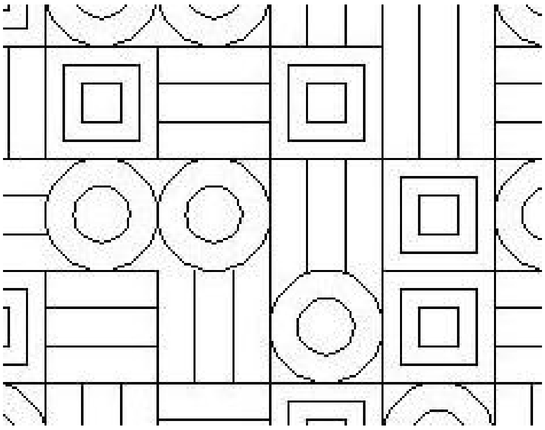

Fig. 4. Sample drawing used for the drawing task.

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. 4. The second part of the questionnaire contained the subjective ratings of the overall comfort level for each thickness. The participants marked their evaluations on a seven-point scale where 1 indicated the least perceived fatigue, or lowest comfort level to use the device at that thickness.

2.5 Experimental Protocol

Seven thicknesses were tested: 0, 10, 20, 30, 40, 50, and 60 mm. The participants were asked to use the experimental device to trace the sample drawings displayed on the simulator at each thickness. After the participants completed the drawing task, they filled out the questionnaire rating fatigue levels of the ten body parts and their overall level of comfort, 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 simulator which was placed on a 73cm high table. They picked up the black pen in one hand and placed their elbows on the table in their most natural drawing posture to start tracing the sample drawing. The time spent to complete the drawing task at each thickness was recorded.

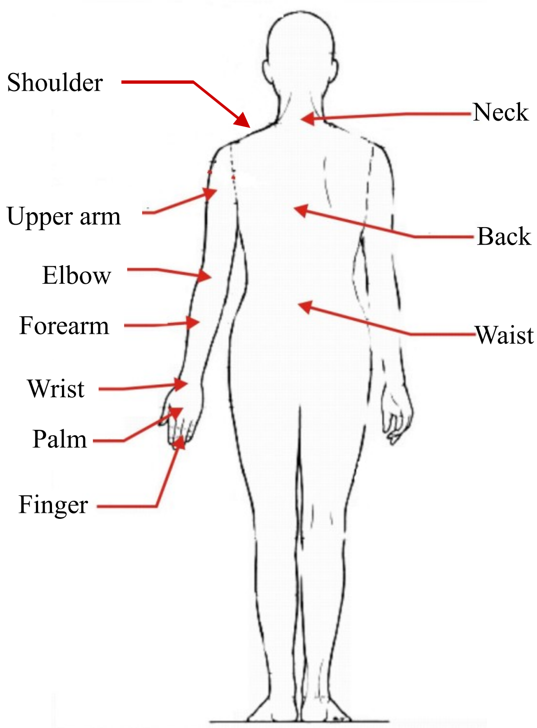

Fig. 5. Body parts rated for the level of fatigue.

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 thickness was tested with each participant per day, i.e., the complete experiment took each participant seven days to complete. The thickness 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 thicknesses 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 seven different thicknesses. Difference analyses were also performed using the *t*-test and repeated measures 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, and overall level of comfort due to gender and thickness, 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, 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 seven different operating thicknesses. 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 upper-arm at 20 mm and palm at 50 mm, 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. 6 shows the distribution of the fatigue level of the ten body parts of all participants at different simulator thicknesses. It can be found that the participants experienced most fatigue in the wrist and shoulder, more fatigue in the finger, forearm, upper arm, and palm, less fatigue in the elbow and neck, and the least fatigue in the back and waist.

From Fig. 6 it can be also found that the fatigue level had a minimum value at about 0 mm for the forearm, elbow and upper arm, 10 mm for the finger, palm, wrist, shoulder, neck and waist, and 20 mm for the back. Greater than the thickness with the minimum value of fatigue level, most of the ten body parts increased gradually with increasing thickness.

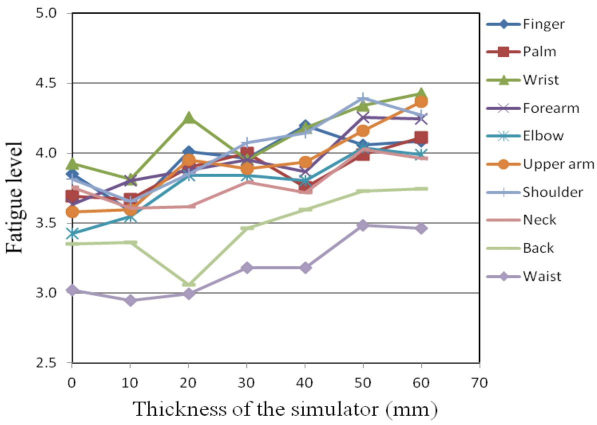

Fig. 6. Distribution of fatigue levels of the ten body parts at different simulator thicknesses.

Table 2 shows ANOVAs results for the fatigue levels of the different body parts at different simulator thicknesses. It reveals that the fatigue levels were not significantly affected by the thickness of the simulator for the finger, palm, and neck. However, the thickness had a significant effect on the fatigue levels of the other seven body parts. Multiple comparisons with the least significant difference (LSD) method showed that the fatigue levels of most of the other seven body parts at 0 mm and 10 mm were significant lower than those at 50 mm and 60 mm.

3.2 Overall Level of Comfort, and Operational Performance

3.2.1 Overall Level of Comfort

Table 3 shows the participants' awareness of the overall level of comfort at the seven different operating thicknesses 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 thickness with the best overall level of comfort was 0 mm (M = 5.00), and the worst was 60 mm (M = 3.40). The results for males and females were not significantly different according to the *t*-test.

Table 1. Mean (SD) fatigue levels★ of the ten body parts at different simulator thicknesses

Thickness (mm)	Gender/ *t*-test	Finger	Palm	Wrist	Fore-arm	Elbow	Upper arm	Shoulder	Neck	Back	Waist
0	Total	3.85 (1.40)	3.69 (1.20)	3.93 (1.37)	3.63 (1.13)	3.42 (1.17)	3.58 (0.99)	3.82 (1.13)	3.75 (1.18)	3.35 (1.08)	3.02 (1.20)
	Male	3.65 (1.16)	3.97 (1.19)	4.00 (1.48)	3.70 (1.14)	3.39 (1.22)	3.54 (0.92)	3.64 (1.08)	3.65 (1.14)	3.24 (1.07)	2.72 (1.08)
	Female	4.05 (1.61)	3.43 (1.18)	3.86 (1.29)	3.57 (1.15)	3.45 (1.15)	3.62 (1.08)	3.97 (1.17)	3.86 (1.25)	3.45 (1.11)	3.31 (1.26)
	Sig. p☆	0.407	0.181	0.764	0.748	0.884	0.830	0.397	0.606	0.576	0.144
10	Total	3.58 (1.22)	3.67 (0.81)	3.82 (0.99)	3.80 (0.90)	3.55 (0.93)	3.60 (0.78)	3.66 (0.89)	3.61 (1.12)	3.36 (1.08)	2.95 (0.91)
	Male	3.47 (1.36)	3.77 (1.00)	3.62 (0.96)	3.80 (0.83)	3.34 (0.91)	3.47 (0.69)	3.67 (1.08)	3.75 (1.31)	3.19 (0.98)	2.82 (0.81)
	Female	3.69 (1.10)	3.57 (0.59)	4.00 (1.01)	3.81 (0.98)	3.74 (0.93)	3.71 (0.86)	3.64 (0.69)	3.48 (0.91)	3.52 (1.18)	3.07 (1.01)
	Sig. p	0.601	0.474	0.264	0.973	0.215	0.363	0.928	0.479	0.373	0.417
20	Total	4.01 (1.31)	3.90 (1.13)	4.26 (1.12)	3.88 (0.96)	3.84 (1.00)	3.95 (0.96)	3.85 (1.10)	3.62 (1.20)	3.05 (1.00)	3.00 (1.18)
	Male	3.80 (1.32)	3.90 (1.27)	4.20 (1.14)	3.70 (0.88)	3.87 (1.05)	3.62 (0.86)	3.67 (1.31)	3.52 (1.21)	2.87 (1.13)	2.99 (1.31)
	Female	4.21 (1.31)	3.90 (1.02)	4.31 (1.12)	4.05 (1.02)	3.81 (0.99)	4.26 (098)	4.02 (0.88)	3.71 (1.21)	3.24 (0.84)	3.00 (1.08)
	Sig. p	0.357	0.987	0.779	0.286	0.856	**0.048***	0.364	0.641	0.277	0.988
30	Total	3.96 (1.29)	4.00 (1.31)	3.95 (1.09)	3.95 (0.93)	3.84 (0.98)	3.89 (0.80)	4.07 (0.80)	3.79 (1.02)	3.46 (1.21)	3.18 (1.26)
	Male	3.87 (1.25)	4.18 (1.31)	3.85 (1.34)	3.77 (0.89)	3.65 (1.00)	3.87 (0.90)	3.95 (0.82)	3.75 (0.81)	3.60 (0.99)	3.19 (1.34)
	Female	4.05 (1.35)	3.83 (1.32)	4.05 (0.83)	4.12 (0.97)	4.02 (0.95)	3.90 (0.73)	4.19 (0.80)	3.83 (1.21)	3.33 (1.41)	3.17 (1.22)
	Sig. p	0.697	0.446	0.600	0.280	0.258	0.915	0.384	0.809	0.531	0.951
40	Total	4.20 (1.21)	3.75 (1.08)	4.18 (1.09)	3.86 (094)	3.80 (0.87)	3.94 (0.96)	4.15 (1.13)	3.72 (1.09)	3.59 (1.13)	3.18 (0.95)
	Male	4.05 (1.36)	3.90 (1.32)	4.13 (1.25)	3.85 (0.76)	3.87 (0.81)	3.92 (0.75)	4.03 (1.02)	3.60 (0.95)	3.80 (1.25)	3.12 (1.07)
	Female	4.33 (1.06)	3.62 (0.80)	4.24 (0.95)	3.88 (1.11)	3.74 (0.93)	3.95 (1.16)	4.26 (1.24)	3.83 (1.21)	3.40 (1.00)	3.24 (0.85)
	Sig. p	0.496	0.450	0.768	0.918	0.653	0.933	0.544	0.528	0.312	0.713
50	Total	4.06 (1.26)	3.99 (1.08)	4.34 (0.86)	4.26 (0.98)	4.04 (1.00)	4.16 (1.01)	4.39 (1.05)	4.02 (1.46)	3.73 (1.02)	3.48 (0.99)
	Male	4.15 (1.10)	4.43 (0.92)	4.56 (0.88)	4.30 (0.99)	3.98 (1.12)	3.92 (0.94)	4.08 (1.00)	3.87 (1.30)	3.72 (0.98)	3.63 (1.05)
	Female	3.98 (1.41)	3.57 (1.08)	4.14 (0.81)	4.21 (0.99)	4.10 (0.91)	4.38 (1.05)	4.69 (1.04)	4.17 (1.62)	3.74 (1.08)	3.34 (0.94)
	Sig. p	0.686	**0.017***	0.157	0.796	0.729	0.184	0.083	0.561	0.968	0.435
60	Total	4.09 (1.23)	4.11 (1.31)	4.43 (1.02)	4.25 (0.90)	3.99 (1.16)	4.37 (1.09)	4.27 (1.17)	3.96 (1.29)	3.74 (1.15)	3.46 (1.09)
	Male	4.25 (1.30)	4.43 (1.41)	4.40 (0.93)	4.35 (0.81)	3.82 (1.27)	4.33 (1.16)	4.13 (1.26)	3.85 (1.32)	3.80 (1.28)	3.45 (1.03)
	Female	3.93 (1.18)	3.81 (1.17)	4.45 (1.13)	4.14 (1.00)	4.14 (1.06)	4.40 (1.04)	4.41 (1.09)	4.17 (1.29)	3.69 (1.06)	3.48 (1.18)
	Sig. p	0.446	0.165	0.891	0.497	0.424	0.839	0.486	0.619	0.786	0.936

★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 $p < 0.05$.

Table 2. ANOVA for mean fatigue levels at different simulator thicknesses

	F value	*P* value	LSD post-hoc test
Finger	2.024	0.064	—
Palm	1.471	0.190	—
Wrist	3.470	0.007☆	0<60; 10<20, 40, 50, 60; 30<50,60 mm
Forearm	3.347	0.008☆	0, 10, 20<50, 60；40<50 mm
Elbow	2.573	0.020★	0, 10<50, 60 mm
Upper arm	4.886	0.000*	0, 10<20, 50, 60; 10<30; 20, 30, 40<60 mm
Shoulder	3.818	0.001☆	0, 20<50, 60; 10<30, 40, 50, 60 mm
Neck	1.185	0.320	—
Back	3.135	0.015★	10<50; 20<30, 40, 50, 60 mm
Waist	2.946	0.021★	0, 10, 20<50, 60 mm

★ Significant at 0.05 level.
☆ Significant at 0.01 level.
*Significant at 0.001 level.

Table 3. Overall level of comfort★ at different simulator thicknesses

Thickness (mm)	Male (n=17)		Female (n=18)		Total (n=35)		*Sig. p*☆ (2-tailed)
	Mean	SD	Mean	SD	Mean	SD	
0	4.94	1.03	5.06	1.21	5.00	1.11	0.766
10	4.59	0.87	4.50	0.71	4.54	0.78	0.743
20	4.06	0.83	4.44	0.78	4.26	0.82	0.166
30	4.00	0.87	4.17	0.99	4.09	0.92	0.599
40	3.82	0.53	4.22	1.06	4.03	0.86	0.168
50	3.59	0.80	3.56	1.10	3.57	0.95	0.921
60	3.18	1.33	3.61	1.14	3.40	1.24	0.308

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

Fig. 7 shows that the overall level of comfort decreased with increasing thickness. The results of the difference analysis according to the ANOVA (as shown in Table 4) for the seven different operating thicknesses showed that the overall level of comfort was significantly affected by the thickness of the simulator (p<0.001). Multiple comparisons with the LSD method showed that the comfort levels at 0 mm was significant higher than those at all other thicknesses, 10 mm was significant higher than those at 30, 40, 50 and 60 mm, and 20, 30 and 40 mm were significant higher than those at 50 and 60 mm (as shown in Table 4). This shows that participants did not feel more comfortable when the monitor was thicker.

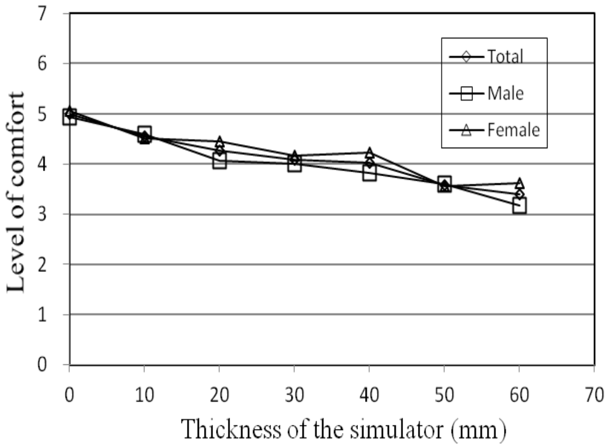

Fig. 7. Overall level of comfort for different simulator thicknesses.

Table 4. ANOVA for mean comfort levels and operational performance at different simulator thicknesses

	F value	*P* value	LSD post-hoc test
Level of comfort	12.490	0.000*	0> 10, 20,30,40,50,60 ; 10>30, 40, 50, 60; 20, 30, 40>50, 60 mm
Operational performance	0.357	0.817	—

*Significant at 0.001 level.

3.2.2 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 5 show that for all the participants, the difference of operational performance was small for all the thicknesses tested. The most time-consuming thickness was 40 mm (1417 s) and the least time-consuming was 10 mm (1336 s). The time required by male participants increased as the thickness increased. This was slightly different for females, who required the most time at 0 mm. However, the t-test showed that these differences were not significant (Table 5). In addition, the results of the difference analysis according to the ANOVA (as shown in Table 4) for the seven different operating thicknesses also showed that operational performance was not significantly affected by the thickness of the simulator (p>0.05).

Table 5. Mean time for completing the drawing task at different simulator thicknesses

Thickness (mm)	Male (n=17)		Female (n=18)		Total (n=35)		*Sig. p*☆ (2-tailed)
	Mean time (s)	SD	Mean time (s)	SD	Mean time (s)	SD	
0	1262	372	1518	428	1394	416	0.068
1	1283	500	1386	375	1336	437	0.491
20	1403	549	1336	313	1369	438	0.660
30	1353	724	1423	344	1389	554	0.721
40	1332	468	1498	406	1417	439	0.270
50	1383	469	1429	447	1407	452	0.770
60	1436	515	1392	355	1414	434	0.770

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

IV. DISCUSSION

The wrist and shoulder were the two parts of the body with the highest levels of fatigue awareness, after drawing at all the thicknesses tested. This result is consistent with the study by Kotani and Horii [22], 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.

From the results mentioned earlier and summarized in Table 6, it is clear that the trend distribution of the average fatigue levels of the body parts at different thicknesses (except at 10 mm) appeared in the opposite direction to that of overall level of comfort, and a significant negative correlation exists (as shown in Table 7). This result is consistent with the general recognition that a lower fatigue level means a greater level of overall comfort. In addition, the trend distributions of the average fatigue levels of the body parts and the time required to complete the drawing task for the thickness between 0 mm and 40 mm were similar, and a positive correlation (although not significant) exists (as shown in Table 7). This result is also consistent with the general recognition that a lower fatigue level means the time required to complete the drawing task could be less, i.e., greater operational performance could be achieved.

We might think that having the monitor as thin as possible, to emulate the actual use of pen and paper, would be the preferred thickness. However, although the results showed that the overall level of comfort at 0 mm was better than those of the other thicknesses, the lowest level of fatigue and the highest operational performance occurred at 10 mm, not 0 mm. This means that the thickness of the monitor is not the thinner the better, and it would be no clear difference when the thickness is thin to a specific thickness.

Table 6. Summary of results

Thickness (mm)	Average fatigue level*(n=35)	Mean comfort level (n=35)	Mean time (s) (n=35)
0	3.60	5.00	1394
10	3.56	4.54	1336
20	3.74	4.26	1369
30	3.81	4.09	1389
40	3.84	4.03	1417
50	4.05	3.57	1407
60	4.07	3.40	1414

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

Table 7. Pearson correlation analysis results

	Average Fatigue level	Comfort level	Time required
Average Fatigue level	1.00		
Comfort level	-.950*	1.00	
Time required	.733	-.542	1.00

*Significant at 0.01 level (two-tailed).

From Table 8 it can be found that the differences between the maximum value and the minimum value of the fatigue levels of each of the ten body parts at all the thicknesses tested were not big (the percentage difference ranging from about 12% to 22%). Compared this result with the result (the percentage difference of the fatigue levels ranging from about 24 to 55) obtained in Yen [2], which investigated the effect of monitor's tilt angle on the fatigue levels of the body parts, it reveals that the effect of monitor's thickness on the fatigue levels of the body parts is less than that of monitor's tilt angle.

Although differences between males and females were observed in the fatigue level, the overall level of comfort, and the time required to complete the assigned drawing task, the only statistically significant difference existed for the upper-arm at 20 mm and palm at 50 mm. This indicates that gender had no obvious effect on fatigue level, overall level of comfort, and operational performance. However, according to the above mentioned results, the thickness of the monitor had a significant effect on fatigue level and comfort level, but had no significant effect on operational performance.

Table 8. Max. and min. values of fatigue levels of the ten body parts

	Max. value of fatigue level (thickness)	Min. value of fatigue level (thickness)	Max.-Min.	Percentage difference (Max.-Min./ Min.)
Finger	4.20(60 mm)	3.58(10 mm)	0.62	17.32
Palm	4.11(60 mm)	3.67(10 mm)	0.44	11.99
Wrist	4.43(60 mm)	3.82(10 mm)	0.61	15.97
Forearm	4.26(50 mm)	3.63(0 mm)	0.63	17.36
Elbow	4.04(50 mm)	3.42(0 mm)	0.62	18.13
Upper arm	4.37(60 mm)	3.58(0 mm)	0.79	22.07
Shoulder	4.39(50 mm)	3.66(10 mm)	0.73	19.95
Neck	4.02(50 mm)	3.61(10 mm)	0.41	11.36
Back	3.74(60 mm)	3.06(20 mm)	0.68	22.22
Waist	3.48(50 mm)	2.95(10 mm)	0.53	17.97

V. CONCLUSION

A thickness of about 10 mm was a suitable drawing thickness, based on the level of fatigue, the overall level of comfort, and the operational performance. In addition, when the monitor was between 0 mm and 20 mm, the operational performance, overall level of comfort, and the operational performance were also good. A thickness between 20 mm and 40 mm was tolerable, but thicknesses greater than 40 mm should be avoided for long-term use.

To sum up, the thickness of the monitor is not the thinner the better, and it would be no clear effects on the operation when the thickness is thinner to a specific thin thickness. In addition, although the thickness has a significant effect on the fatigue level of the body parts, the effect is not so big.

The tablet LCD monitor is an increasingly popular product. Due to unable to find the same screen size with the thickness to meet the all thicknesses wanted for the experiment, this study used a simulator for simulating the screen size of a 19" monitor. Therefore, the results obtained in this study may be different from those of the other size monitors to some extent. This could merit to be examined in future studies.

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